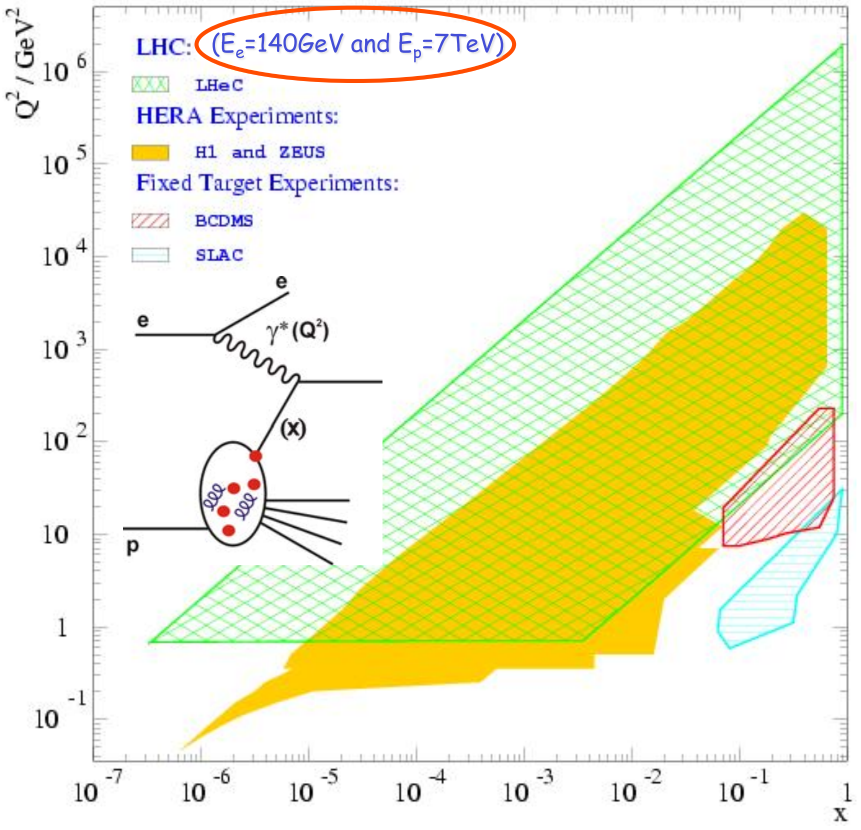
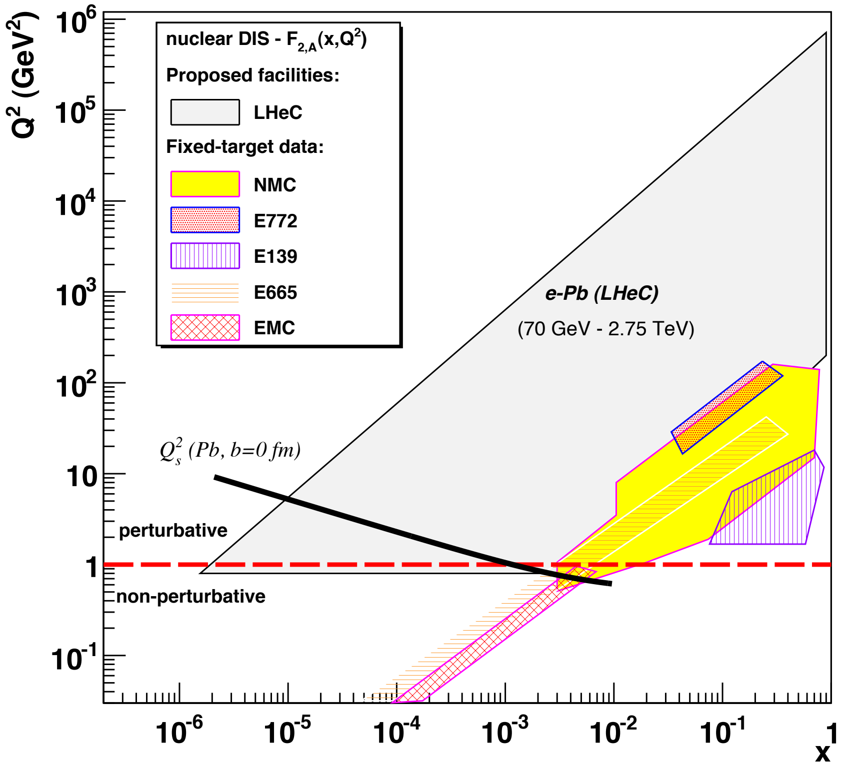


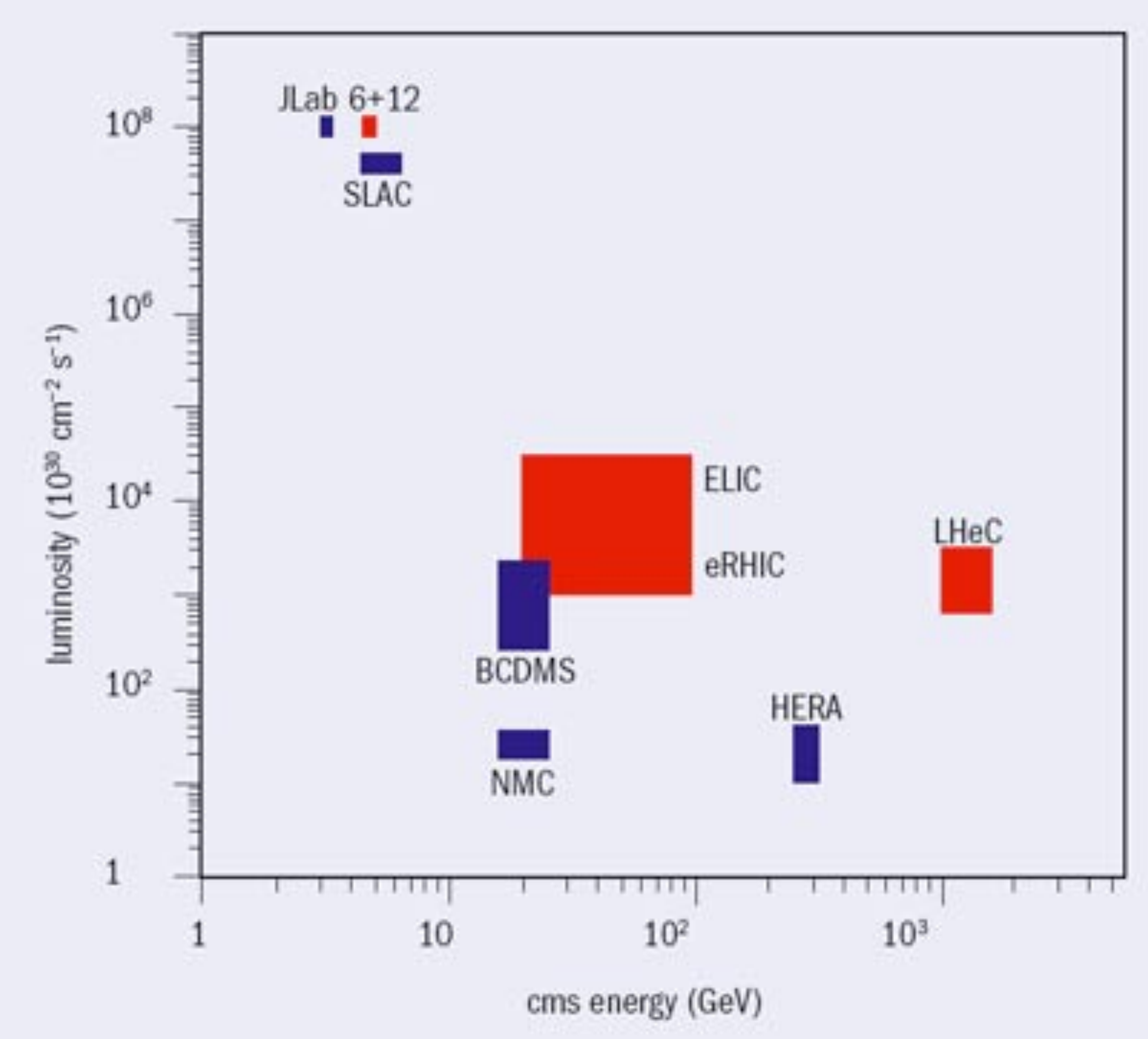
http://cern.ch/lhec

Physics of ep and eA collisions at the LHeC

Anna Stasto (Penn State & RIKEN BNL & Krakow INP)



08/21/2012 POETIC 2012, Bloomington, IN



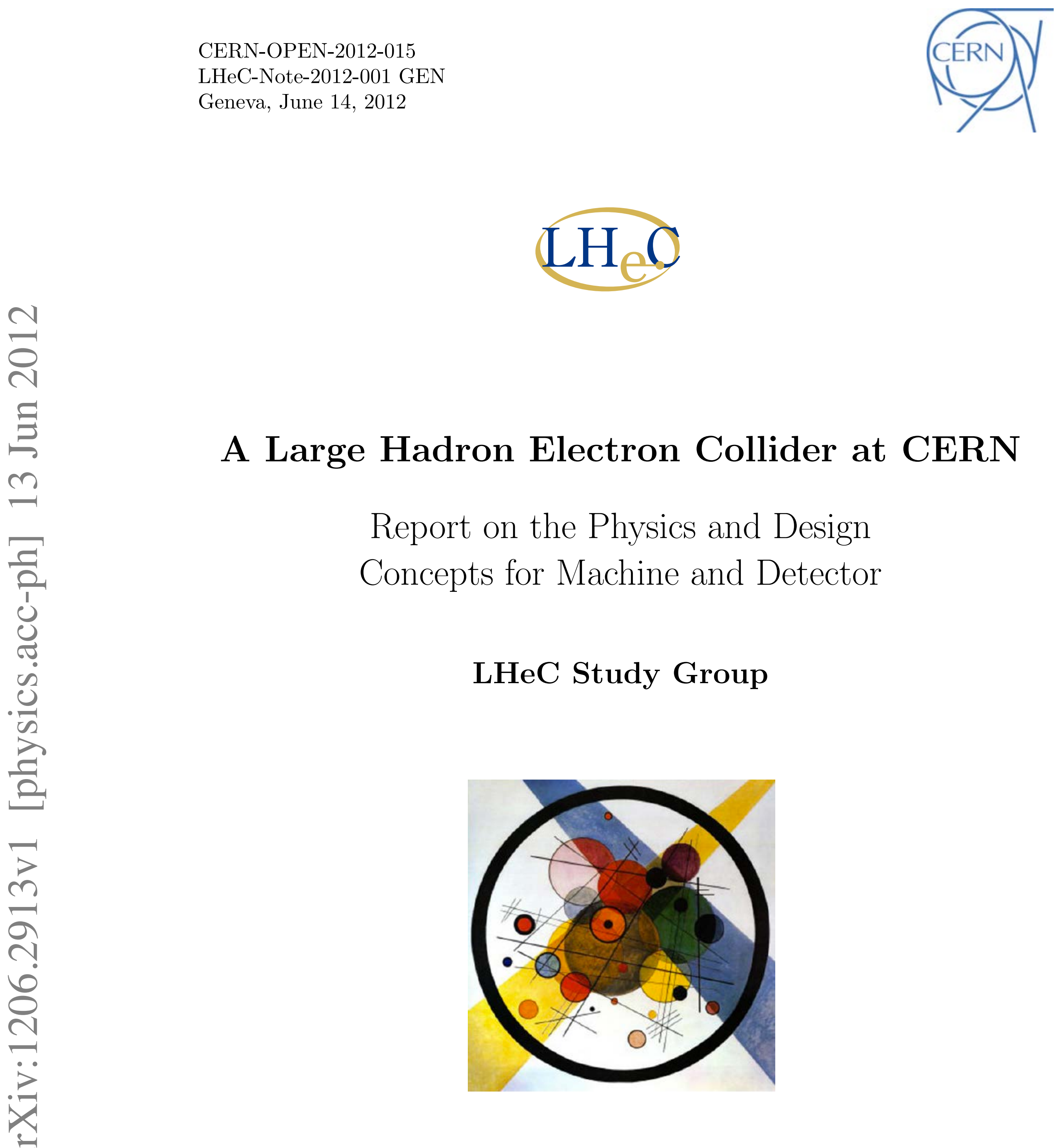
LHeC the latest idea to bring DIS physics to the TeV centre-of-mass scale at high luminosity

Outline of the talk:

- Physics motivation
- Accelerator and detector design
- Physics possibilities
- Timeline and outlook

Conceptual Design Report

All the results presented here are published in CDR



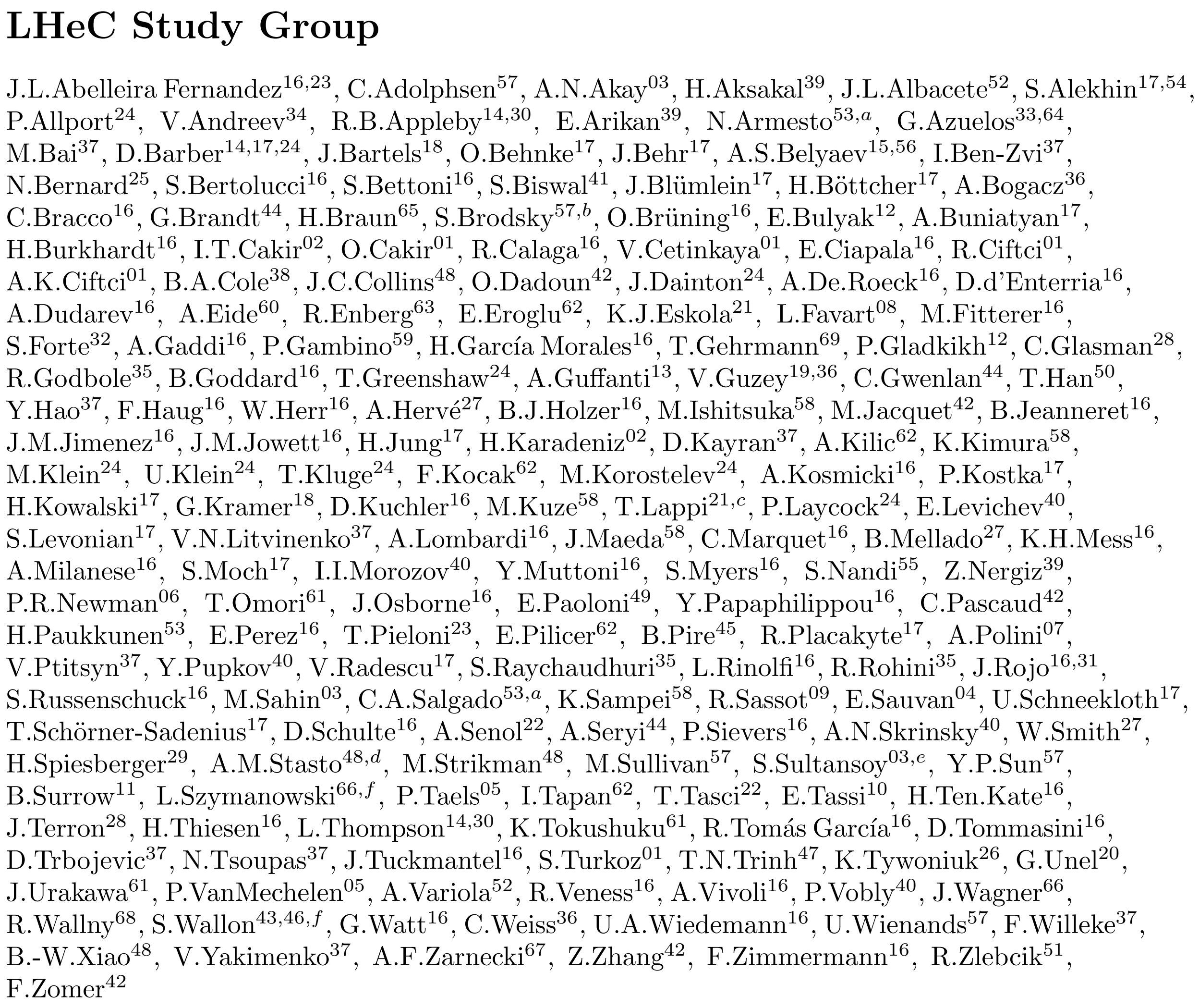
CERN-OPEN-2012-015
LHeC-Note-2012-001 GEN
Geneva, June 14, 2012

arXiv:1206.2913v1 [physics.acc-ph] 13 Jun 2012

A Large Hadron Electron Collider at CERN

Report on the Physics and Design
Concepts for Machine and Detector

LHeC Study Group



LHeC Study Group

J.L.Abelleira Fernandez[16,23], C.Adolphsen[57], A.N.Akay[03], H.Aksakal[39], J.L.Albacete[52], S.Alekhin[17,54], P.Allport[24], V.Andreev[34], R.B.Appleby[14,30], E.Arikan[39], N.Armesto[53,a], G.Azuelos[33,64], M.Bai[37], D.Barber[14,17,24], J.Bartels[18], O.Behnke[17], J.Behr[17], A.S.Belyaev[15,56], I.Ben-Zvi[37], N.Bernard[25], S.Bertolucci[16], S.Bettoni[16], S.Biswal[41], J.Blümlein[17], H.Böttcher[17], A.Bogacz[36], C.Bracco[16], G.Brandt[44], H.Braun[65], S.Brodsky[57,b], O.Brüning[16], E.Bulyak[12], A.Buniatyan[17], H.Burkhardt[16], I.T.Cakir[02], O.Cakir[01], R.Calaga[16], V.Cetinkaya[01], E.Ciapala[16], R.Ciftci[01], A.K.Ciftci[01], B.A.Cole[38], J.C.Collins[48], O.Dadoun[42], J.Dainton[24], A.De.Roeck[16], D.d'Enterria[16], A.Dudarev[16], A.Eide[60], R.Enberg[63], E.Eroglu[62], K.J.Eskola[21], L.Favart[08], M.Fitterer[16], S.Forte[32], A.Gaddi[16], P.Gambino[59], H.García Morales[16], T.Gehrmann[69], P.Gladkikh[12], C.Glasman[28], R.Godbole[35], B.Goddard[16], T.Greenshaw[24], A.Guffanti[13], V.Guzey[19,36], C.Gwenlan[44], T.Han[50], Y.Hao[37], F.Haug[16], W.Herr[16], A.Hervé[27], B.J.Holzer[16], M.Ishitsuka[58], M.Jacquet[42], B.Jeanneret[16], J.M.Jimenez[16], J.M.Jowett[16], H.Jung[17], H.Karadeniz[02], D.Kayran[37], A.Kilic[62], K.Kimura[58], M.Klein[24], U.Klein[24], T.Kluge[24], F.Kocak[62], M.Korostelev[24], A.Kosmicki[16], P.Kostka[17], H.Kowalski[17], G.Kramer[18], D.Kuchler[16], M.Kuze[58], T.Lappi[21,c], P.Laycock[24], E.Levichev[40], S.Levonian[17], V.N.Litvinenko[37], A.Lombardi[16], J.Maeda[58], C.Marquet[16], B.Mellado[27], K.H.Mess[16], A.Milanese[16], S.Moch[17], I.I.Morozov[40], Y.Muttoni[16], S.Myers[16], S.Nandi[55], Z.Nergiz[39], P.R.Newman[06], T.Omori[61], J.Osborne[16], E.Paoloni[49], Y.Papaphilippou[16], C.Pascaud[42], H.Paukkunen[53], E.Perez[16], T.Pieloni[23], E.Pilicer[62], B.Pire[45], R.Placakyte[17], A.Polini[07], V.Ptitsyn[37], Y.Pupkov[40], V.Radescu[17], S.Raychaudhuri[35], L.Rinolfi[16], R.Rohini[35], J.Rojo[16,31], S.Russenschuck[16], M.Sahin[03], C.A.Salgado[53,a], K.Sampei[58], R.Sassot[09], E.Sauvan[04], U.Schneekloth[17], T.Schörner-Sadenius[17], D.Schulte[16], A.Senol[22], A.Seryi[44], P.Sievers[16], A.N.Skrinsky[40], W.Smith[27], H.Spiesberger[29], A.M.Stasto[48,d], M.Strikman[48], M.Sullivan[57], S.Sultansoy[03,e], Y.P.Sun[57], B.Surrow[11], L.Szymanowski[66,f], P.Taels[05], I.Tapan[62], T.Tasci[22], E.Tassi[10], H.Ten.Kate[16], J.Terron[28], H.Thiesen[16], L.Thompson[14,30], K.Tokushuku[61], R.Tomás García[16], D.Tommasini[16], D.Trbojevic[37], N.Tsoupas[37], J.Tuckmantel[16], S.Turkoz[01], T.N.Trinh[47], K.Tywoniuk[26], G.Unel[20], J.Urakawa[61], P.VanMechelen[05], A.Variola[52], R.Veness[16], A.Vivoli[16], P.Vobly[40], J.Wagner[66], R.Wallny[68], S.Wallon[43,46,f], G.Watt[16], C.Weiss[36], U.A.Wiedemann[16], U.Wienands[57], F.Willeke[37], B.-W.Xiao[48], V.Yakimenko[37], A.F.Zarnecki[67], Z.Zhang[42], F.Zimmermann[16], R.Zlebcik[51], F.Zomer[42]

arXiv:1206.2913

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193 authors
631 pages
947 references
5 chapters
14 sections

Physics Motivation for ep/eA in TeV range

- Details of parton structure of the nucleon (from ep,ed/eA), full unfolding of PDFs. Measurement of GPDs and unintegrated PDFs.
- Mapping the gluon field down to very low x. Saturation physics.
- Heavy quarks, factorization, diffraction, electroweak processes.
- Properties of Higgs. Very good sensitivity to: H to bbar, H to WW coupling in the 120-130 GeV mass range.
- Searches and understanding of new physics. Very precise measurement of the coupling constant. Leptoquarks, excited leptons...
- Deep inelastic scattering off nuclei (lead and deuteron). Nuclear parton distributions. Pinning down the initial state for heavy ion collisions.
- Understanding nuclear effects of QCD radiation and hadronization.

LHeC kinematics

ep/eA collisions

$$E_p = 7 \text{ TeV}$$

$$E_A = 2.75 \text{ TeV}/\text{nucleon}$$ lead

$$E_d = 3.5 \text{ TeV}/\text{nucleon}$$ deuteron

$$E_e = 50 - 150 \text{ GeV}$$

$$\sqrt{s} \simeq 1 - 2 \text{ TeV}$$

- Requirements:

* Luminosity~10^{33} cm^{-2}s^{-1}. eA: L_{en}~10^{32} cm^{-2}s^{-1}

* Acceptance: 1-179 degrees (low-x ep/eA).

* Tracking to 1 mrad.

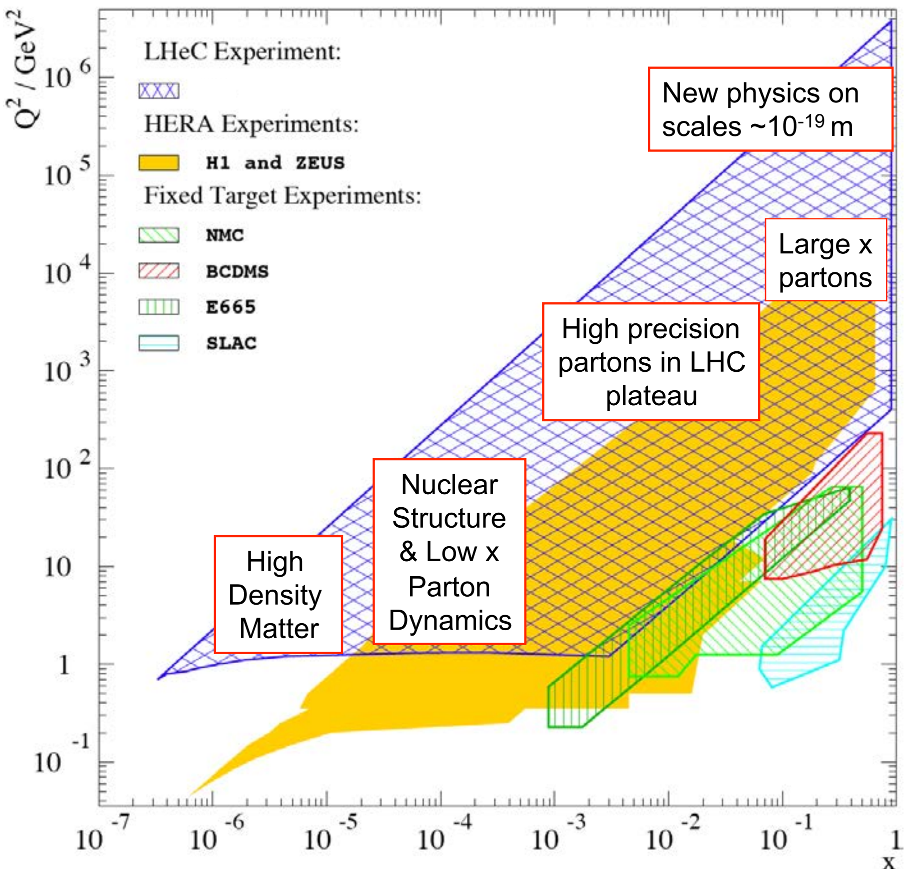
* EMCAL calibration to 0.1 %.

* HCAL calibration to 0.5 %.

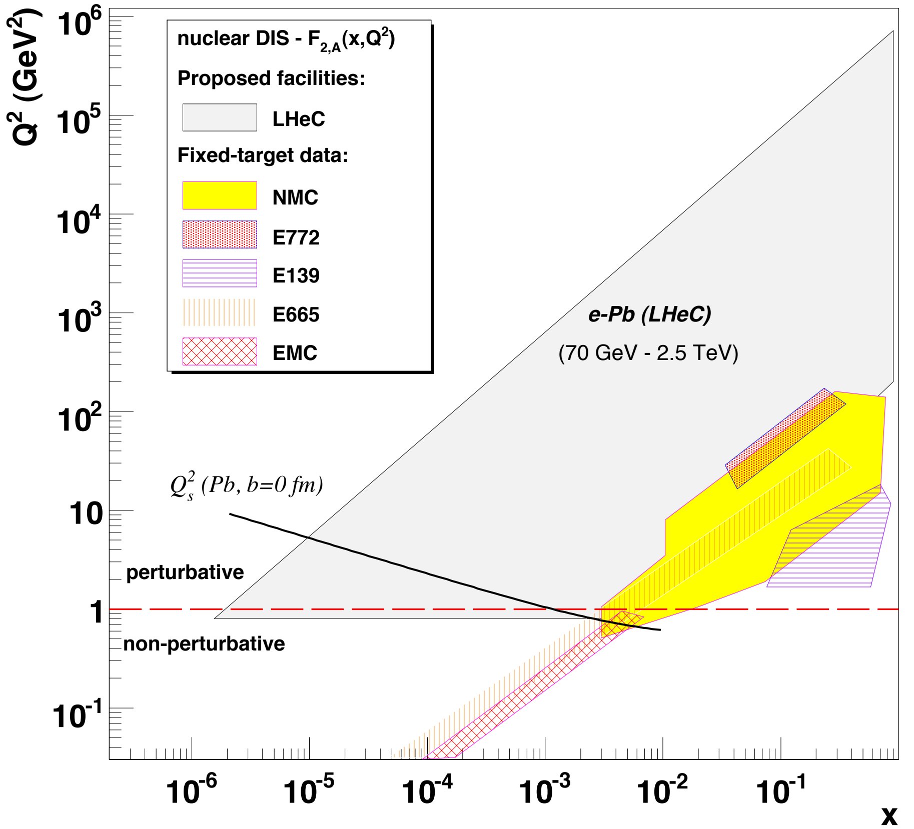
* Luminosity determination to 1 %.

* Compatible with LHC operation.

ep



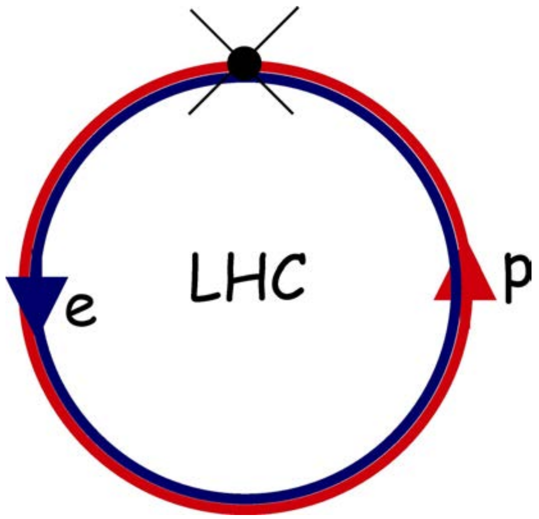
eA



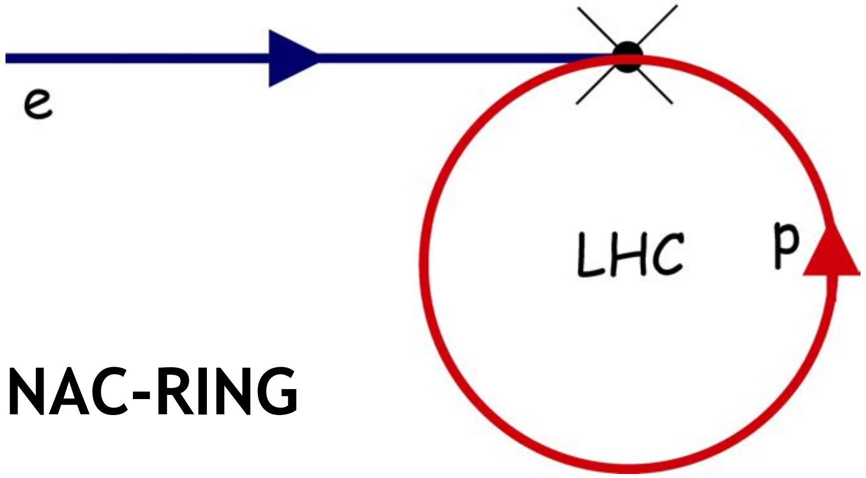
How Could ep be Done using LHC?

… <u>whilst allowing simultaneous ep and pp running</u> …

RING-RING



LINAC-RING



- First considered (as LEPxLHC) in 1984 ECFA workshop

- Main advantage: high peak lumi obtainable (~2.10^{33} cm^{-2} s^{-1})

- Main difficulties: building round existing LHC, e beam energy (60GeV?) and lifetime limited by synchrotron radiation

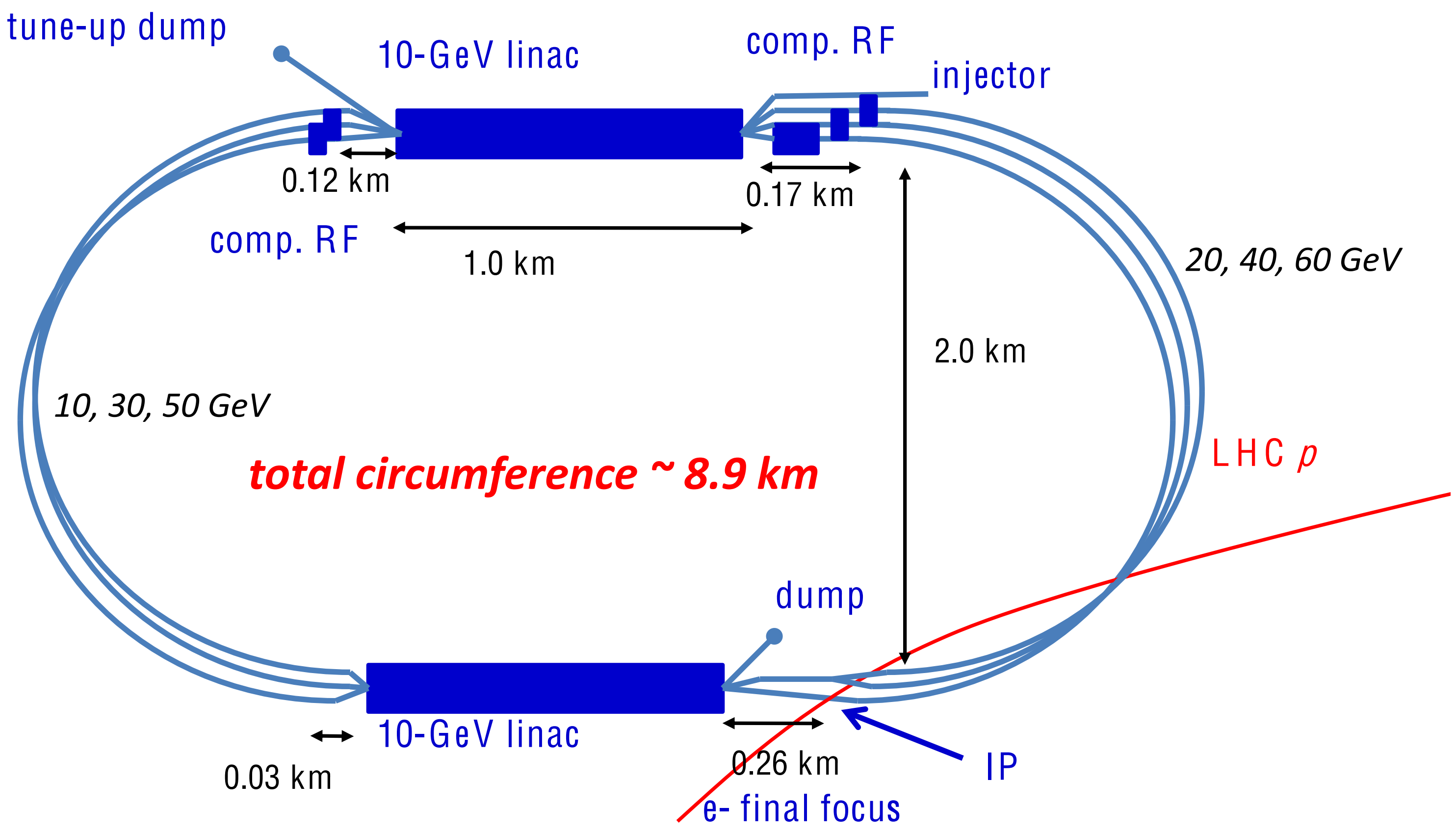
- Previously considered as `QCD explorer' (also THERA)

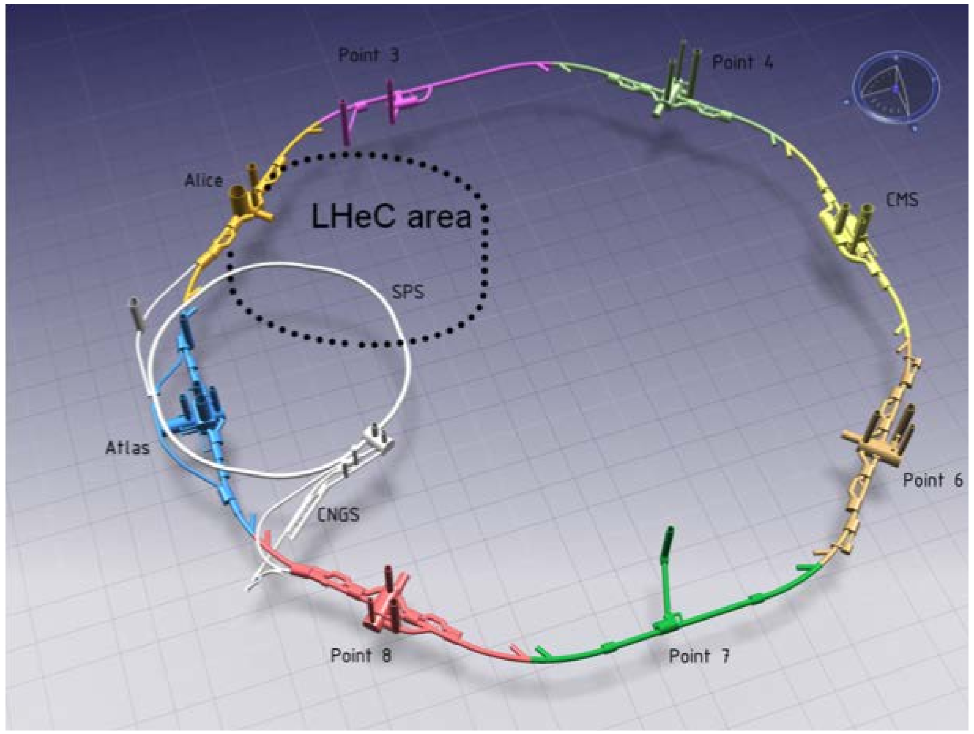
- Main advantages: low interference with LHC, high E_e (→ 150 GeV?) and lepton polarisation, LC relation

- Main difficulties:
  no previous experience exists

preferred option

Accelerator design in linac-ring option



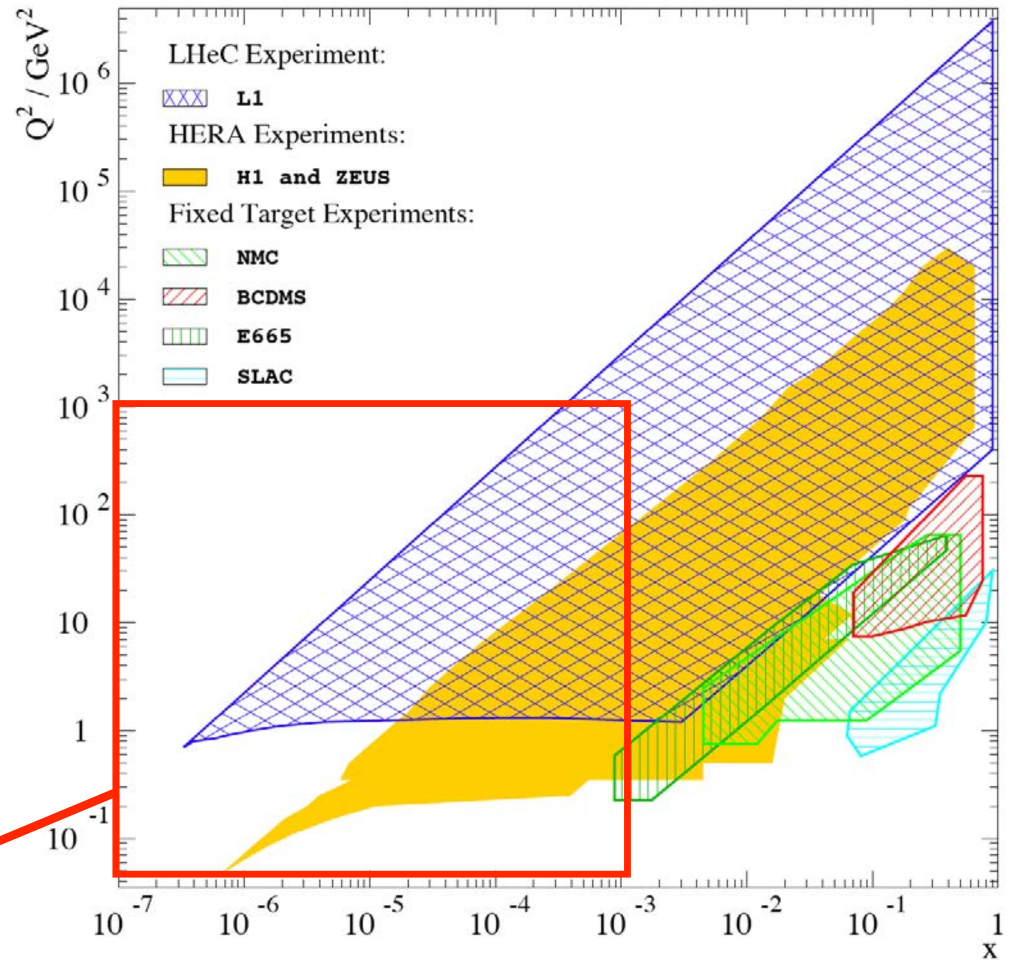


500 MeV injection, 3 turns, 2 linacs, 10 GeV
energy recovery, 90% polarisation

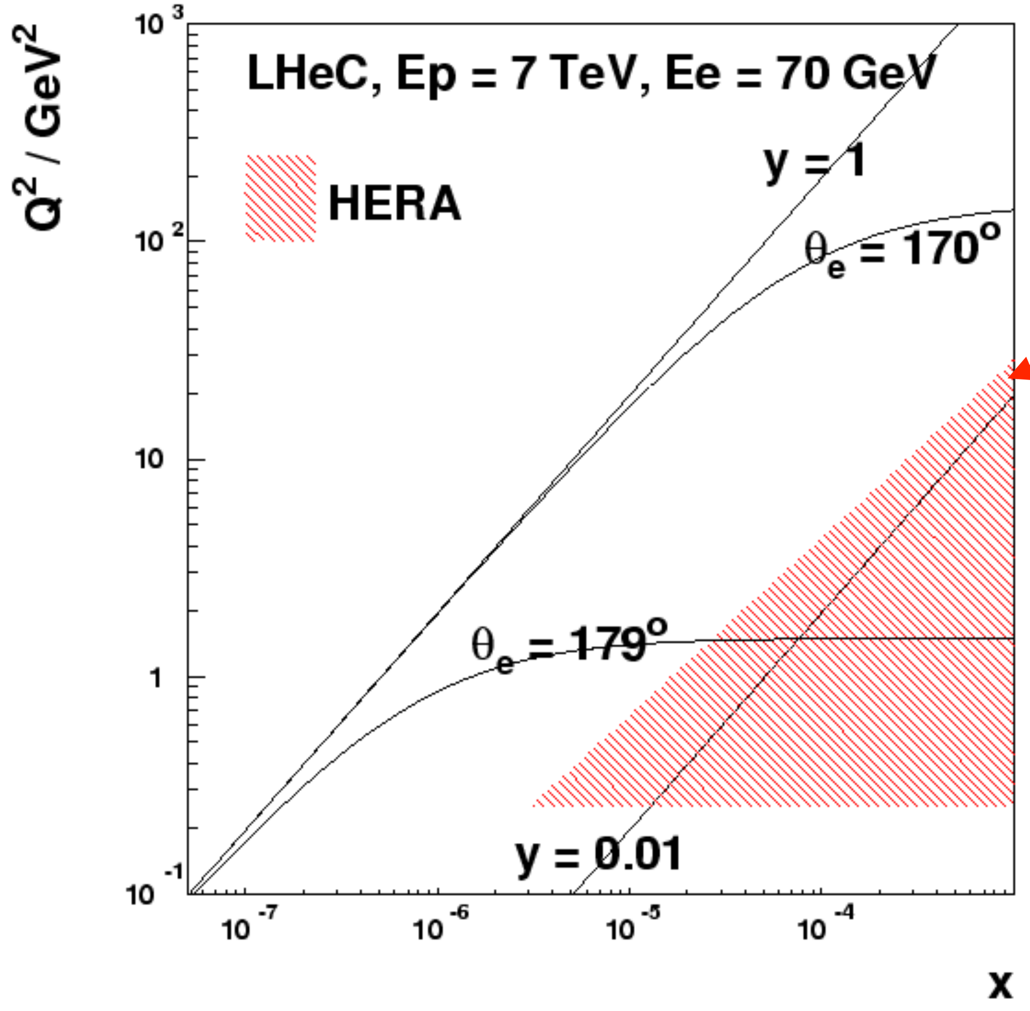
$$L = 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$$

Higher energy:
140 GeV linac
ILC type
31.5 MV/m
without energy recovery
lower luminosity

Detector Acceptance Requirements

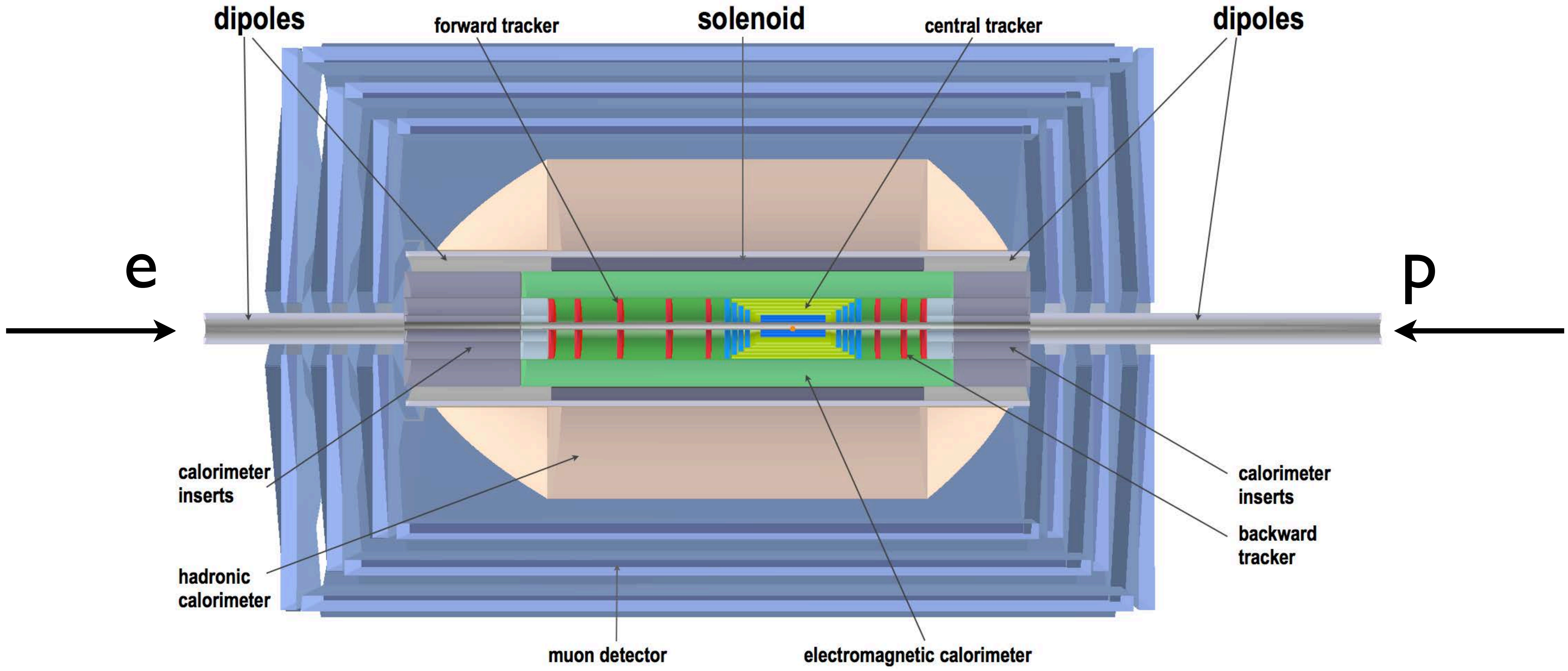


Access to Q^2=1 GeV^2 in ep mode for all x > 5 x 10^{-7} requires scattered electron acceptance to 179°



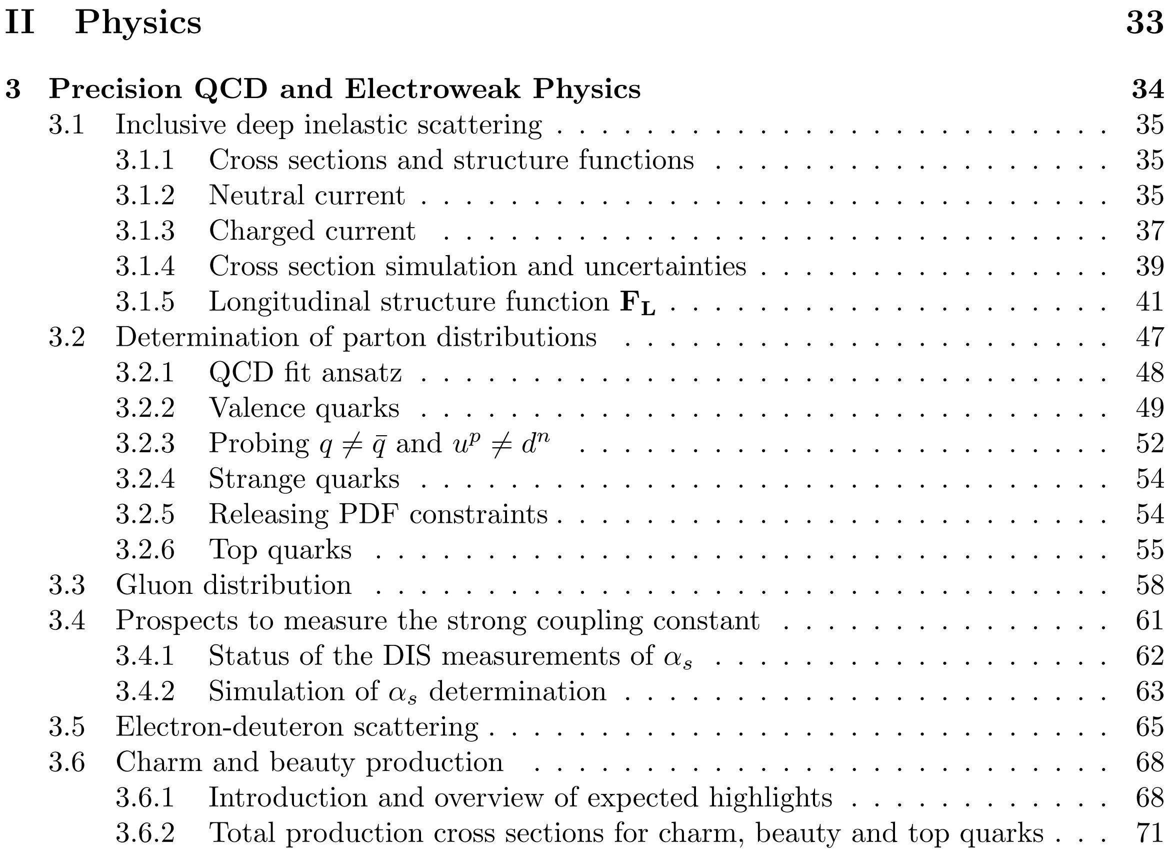
Similarly, need 1° acceptance in outgoing proton direction to contain hadrons at high x (essential for good kinematic reconstruction)

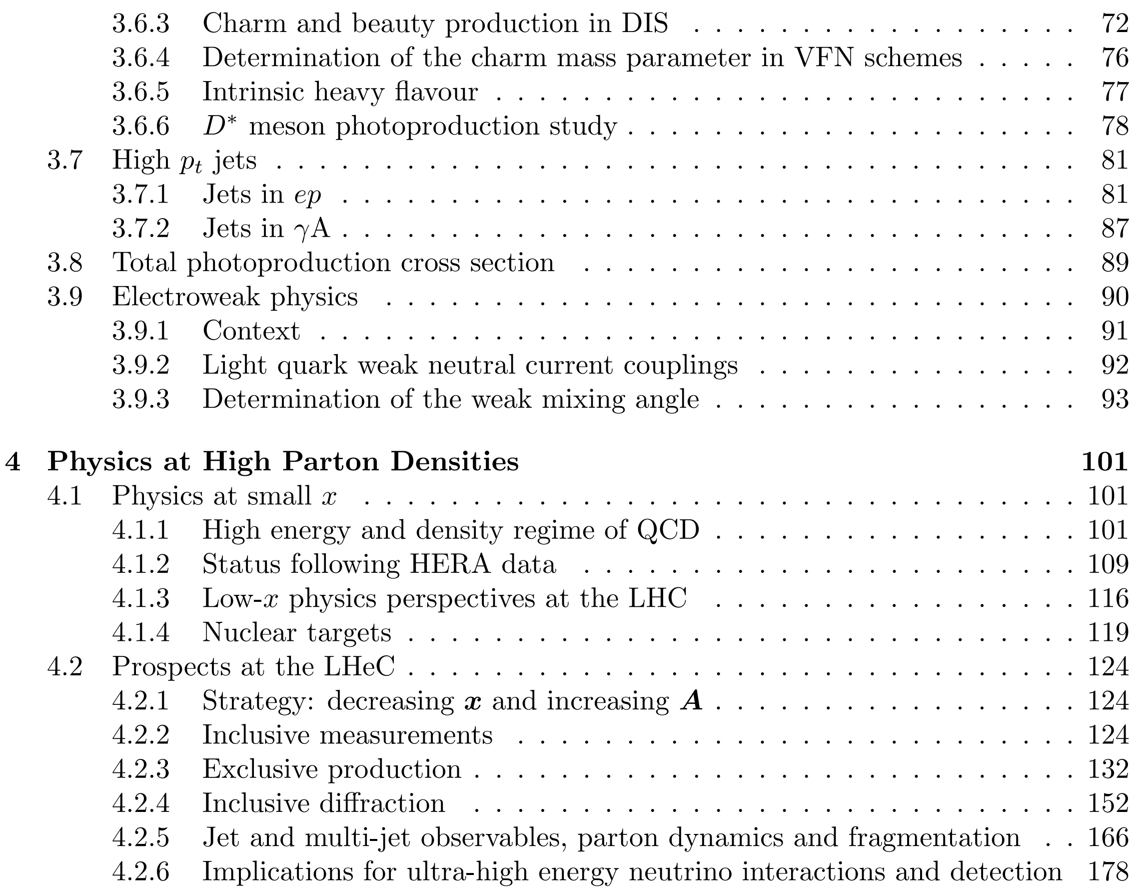
Detector design

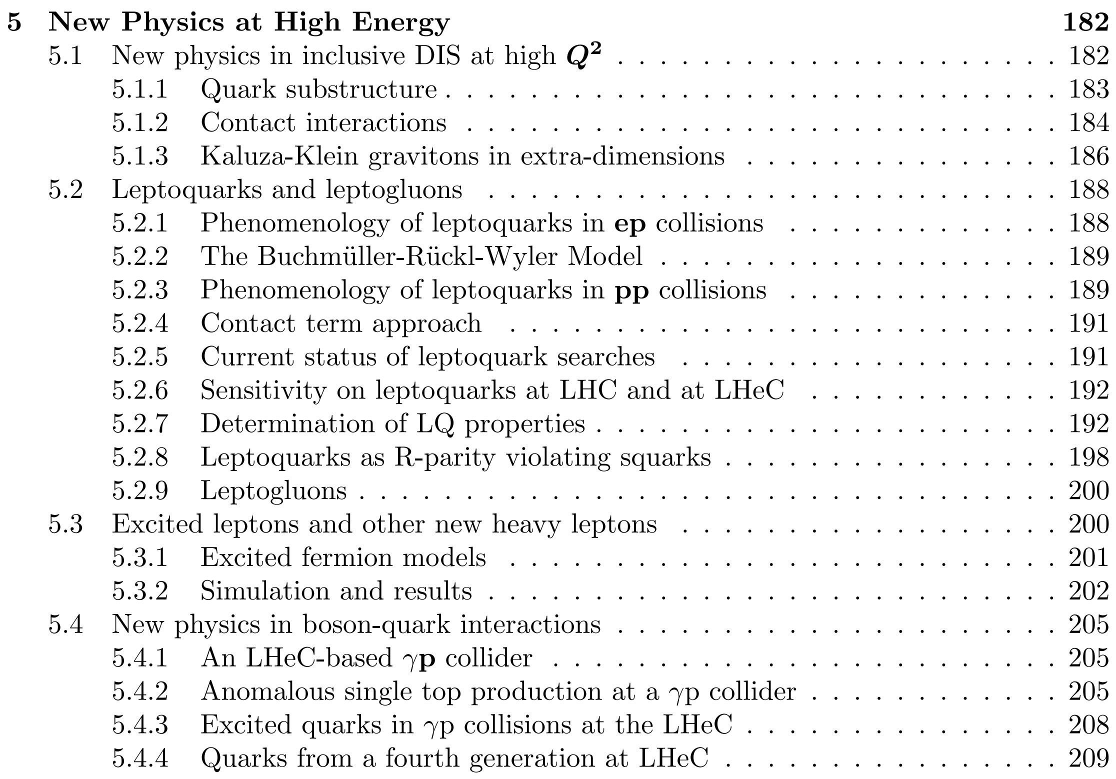


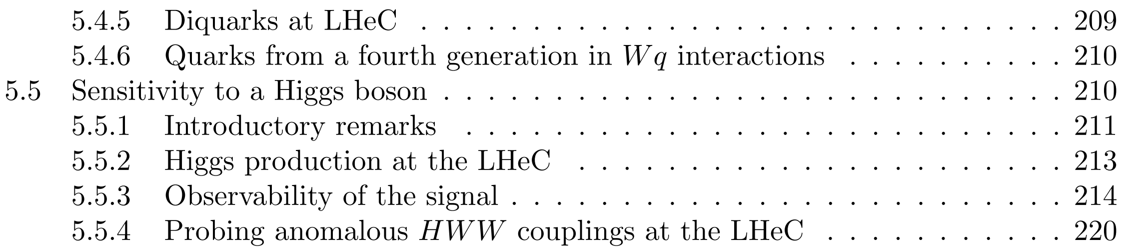
Forward/backward asymmetry in energy deposited and thus in geometry and technology
Present dimensions: LxD =14x9m^2 [CMS 21 x 15m^2 , ATLAS 45 x 25 m^2]
Taggers at -62m (e),100m (γ,LR), -22.4m (γ,RR), +100m (n), +420m (p)

Physics chapter of the CDR

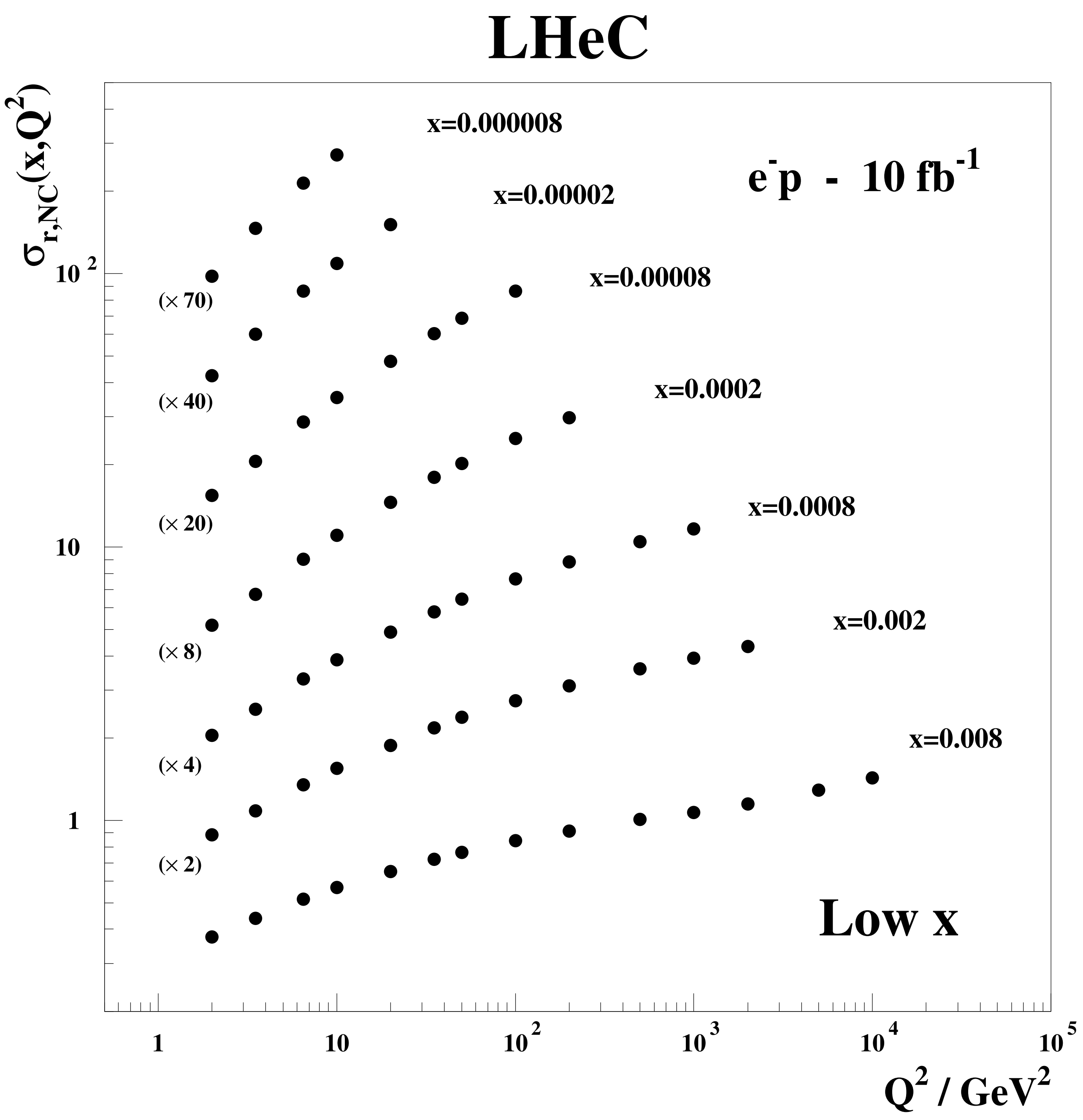


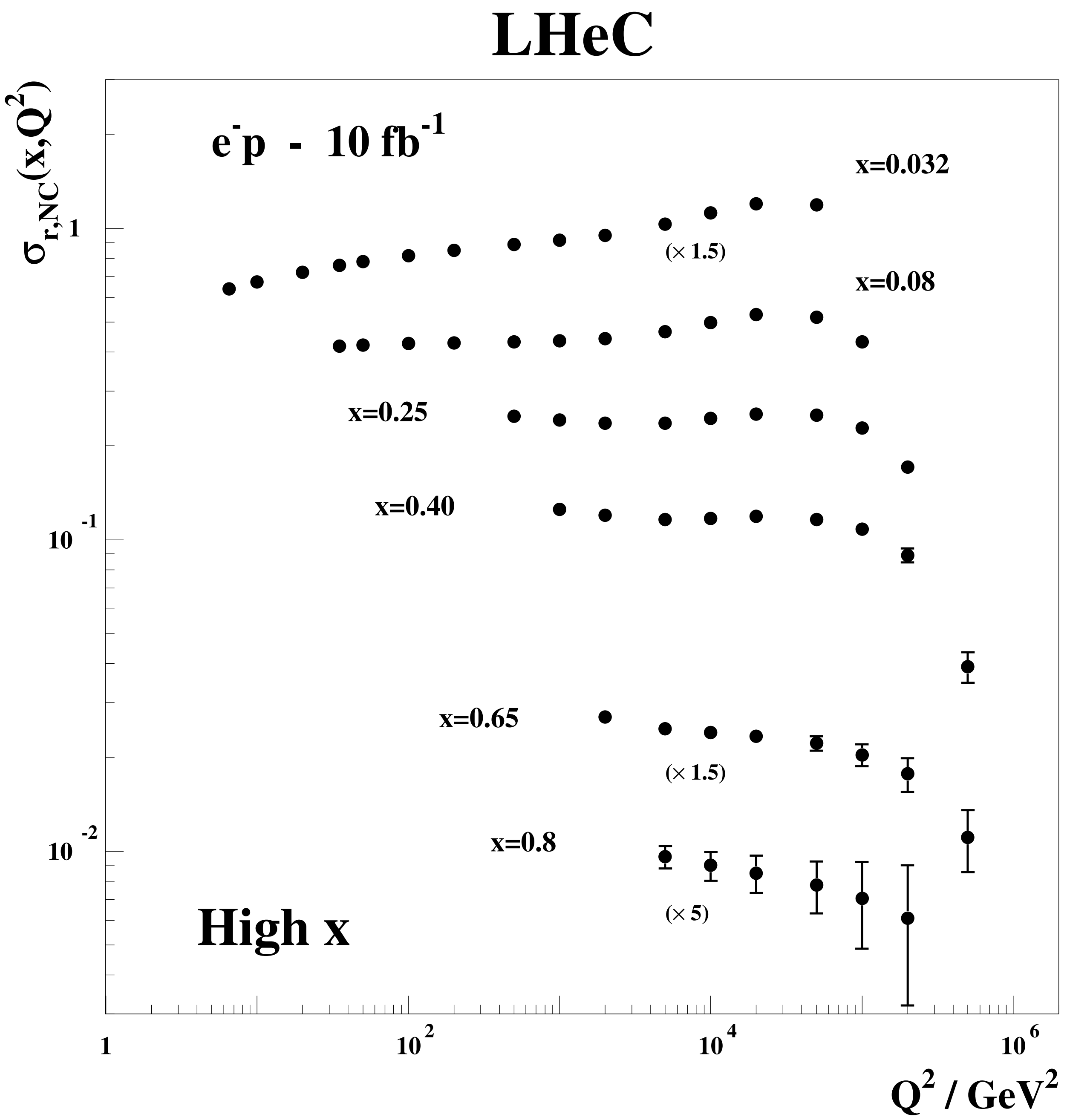






Inclusive measurements





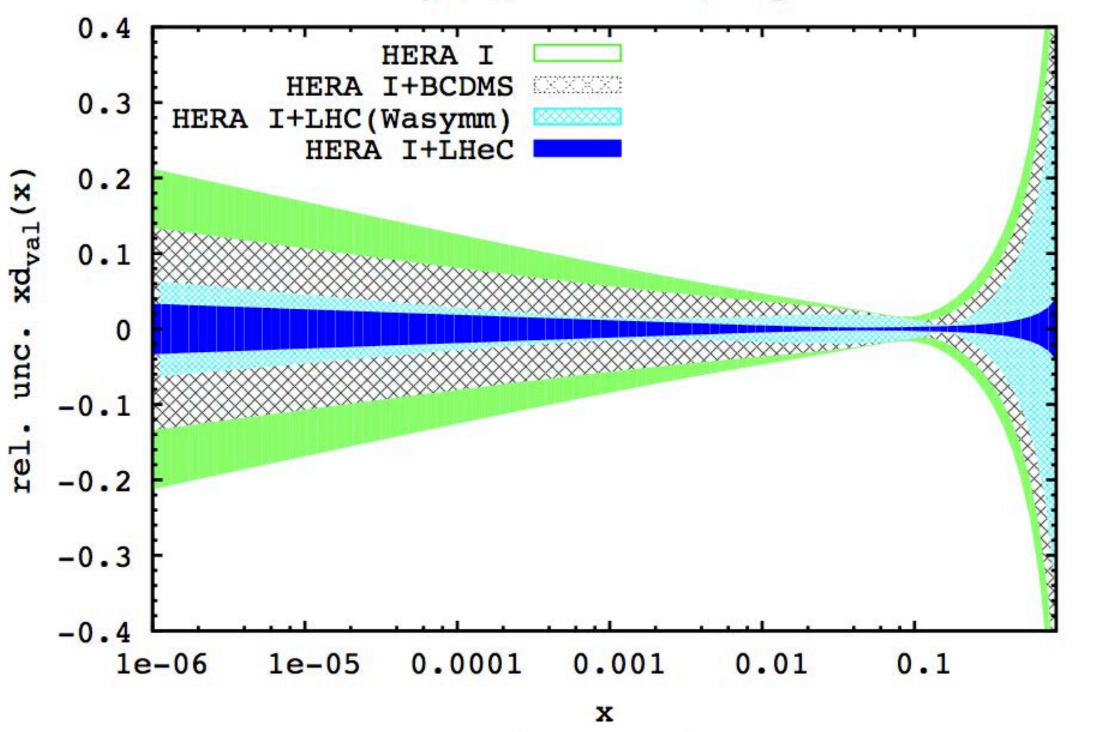
Reduced cross section

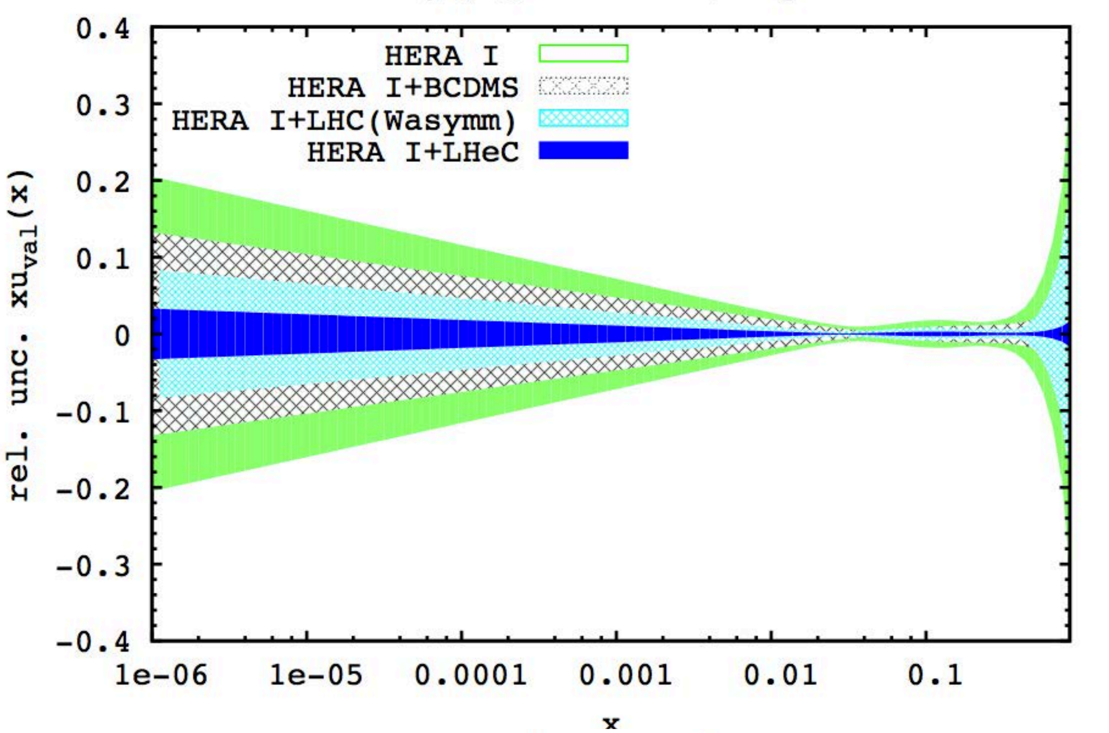
$$\frac{d^2\sigma_{NC}}{dxdQ^2} = \frac{2\pi\alpha^2 Y_+}{Q^4 x} \cdot \sigma_{r,NC}$$

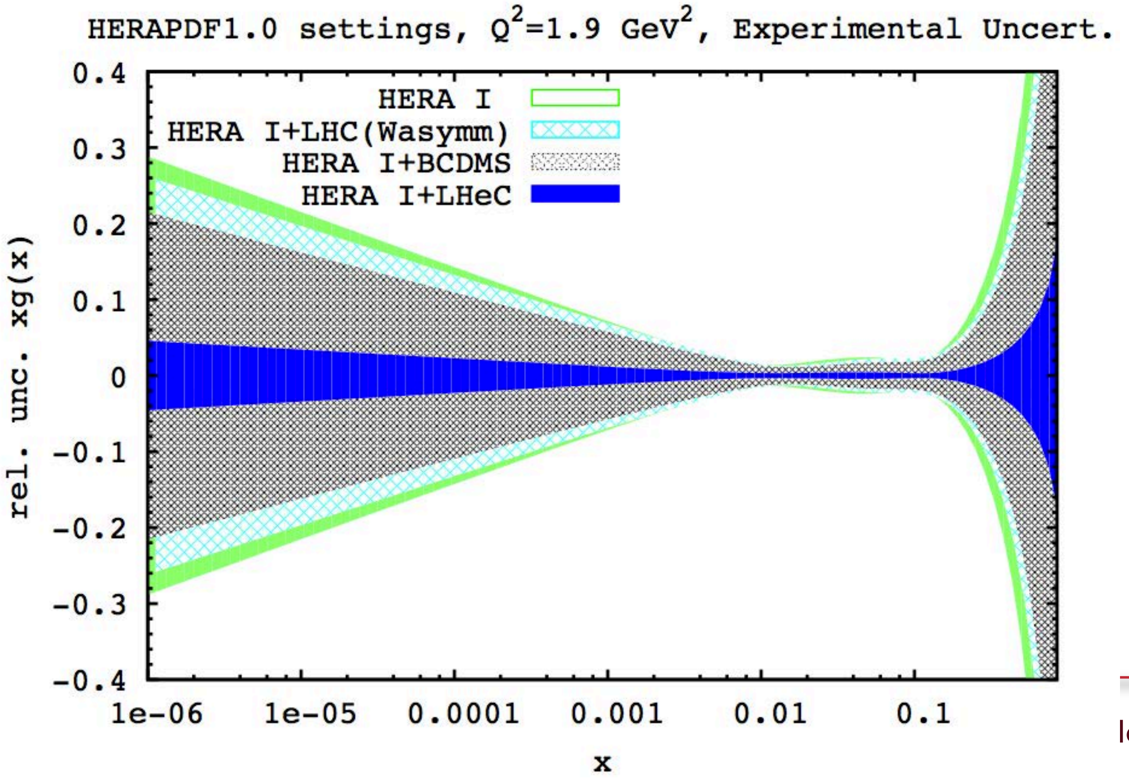
Talk by Voica Radescu in Chavannes-de-Bogis

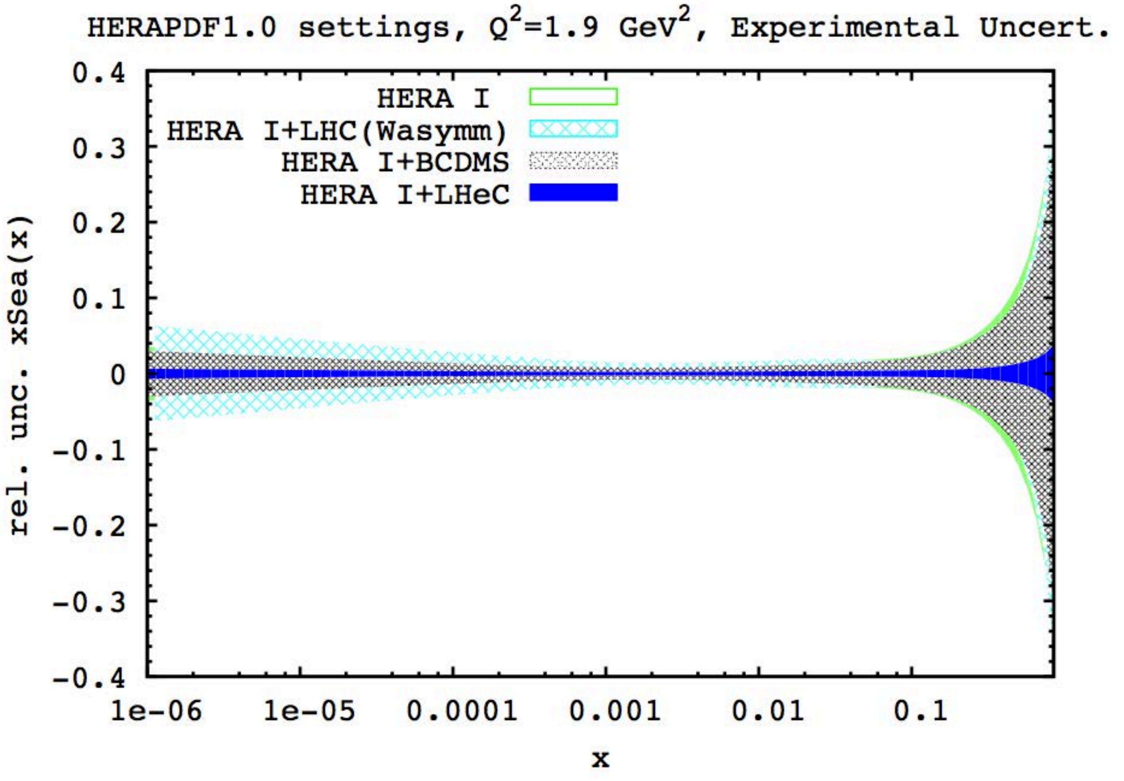
Impact of LHeC on PDFs: zoom on low x

* Experimental uncertainties are shown at the starting scale $Q^2=1.9$ GeV^2









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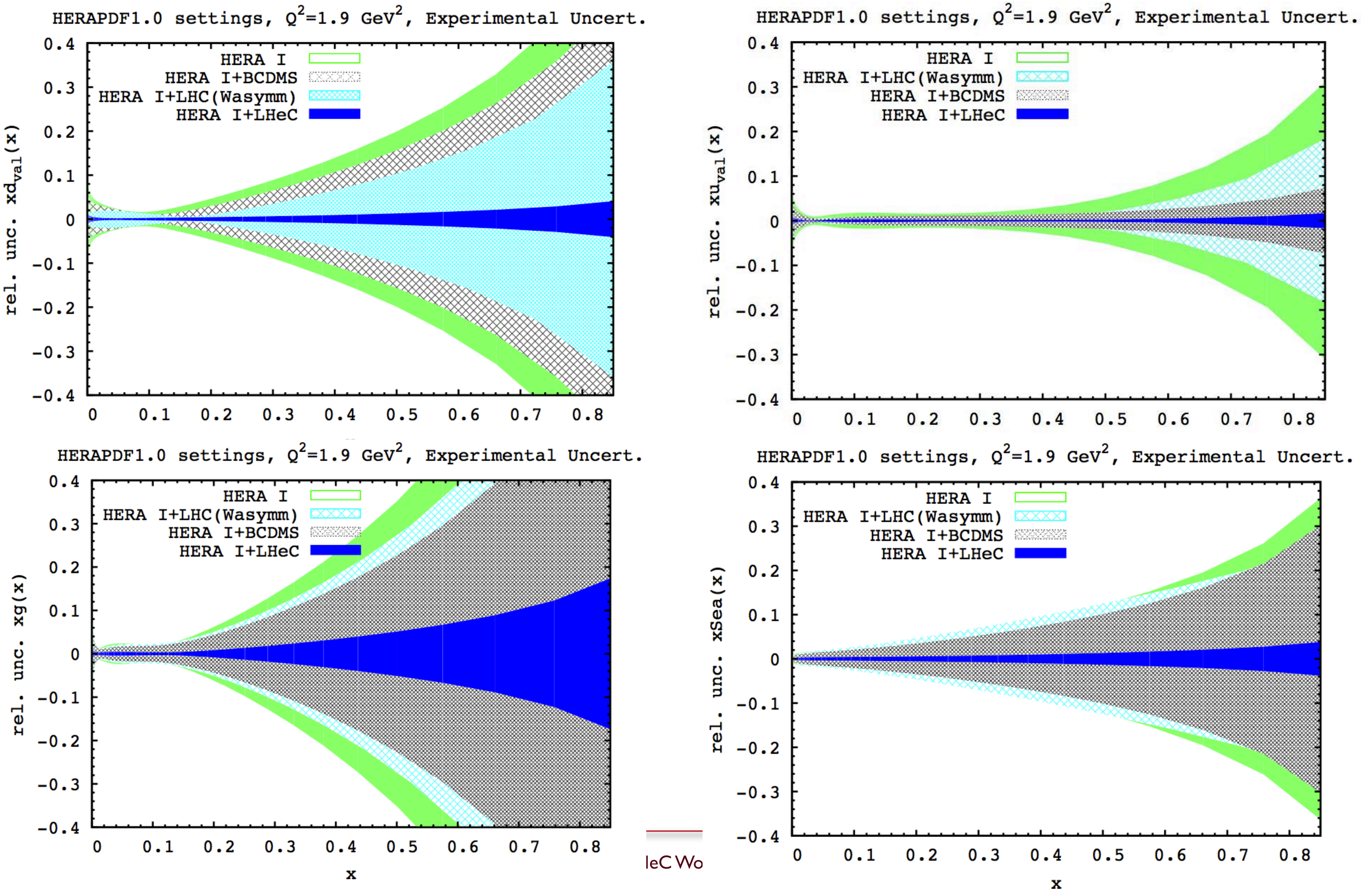


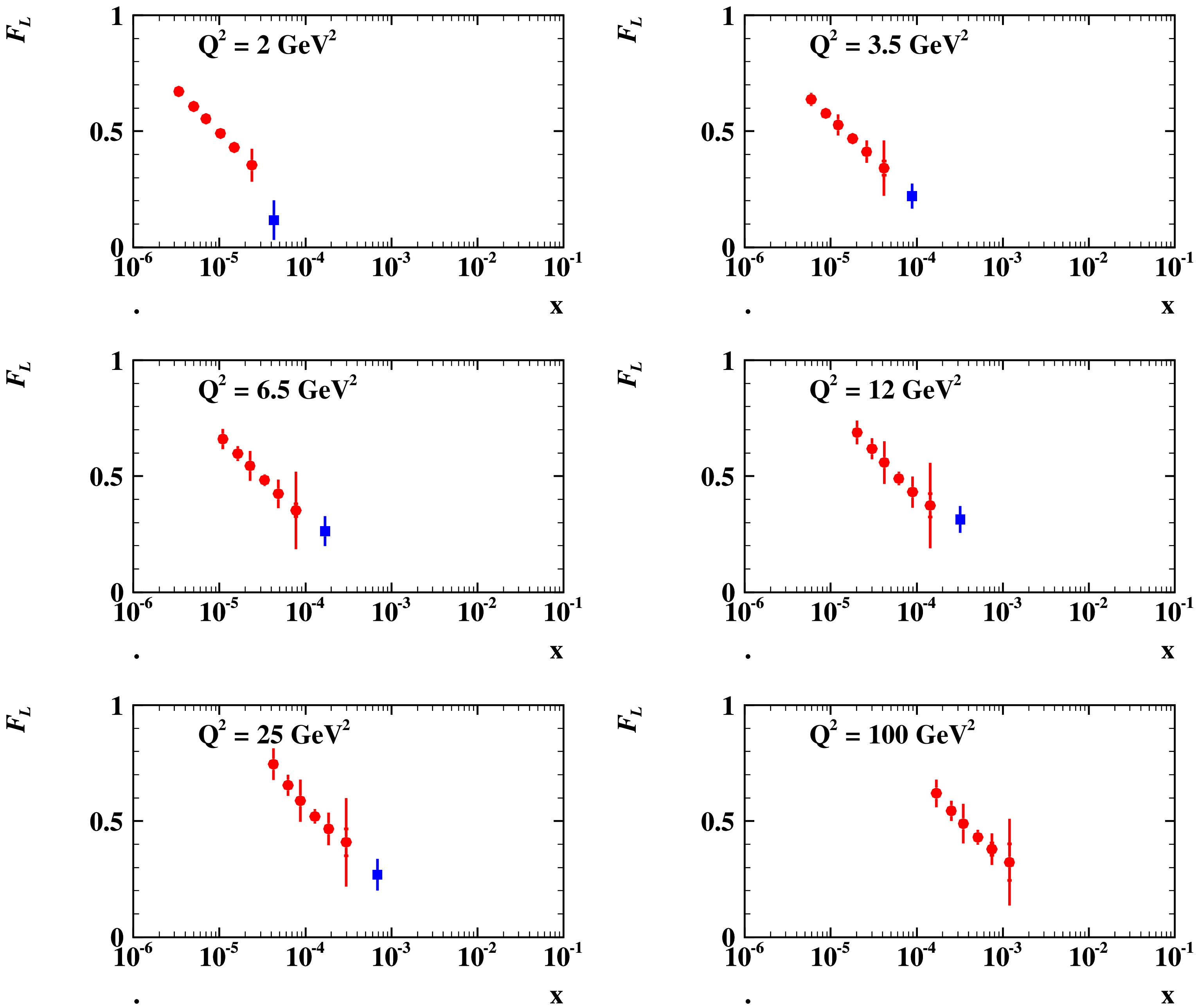
leC Wo

Inclusive measurements

Longitudinal structure function simulation. Electron energies and luminosities:

$$(60, 1), (30, 0.3), (20, 0.1), (10, 0.05) \quad (\mathrm{GeV}, \mathrm{fb}^{-1})$$

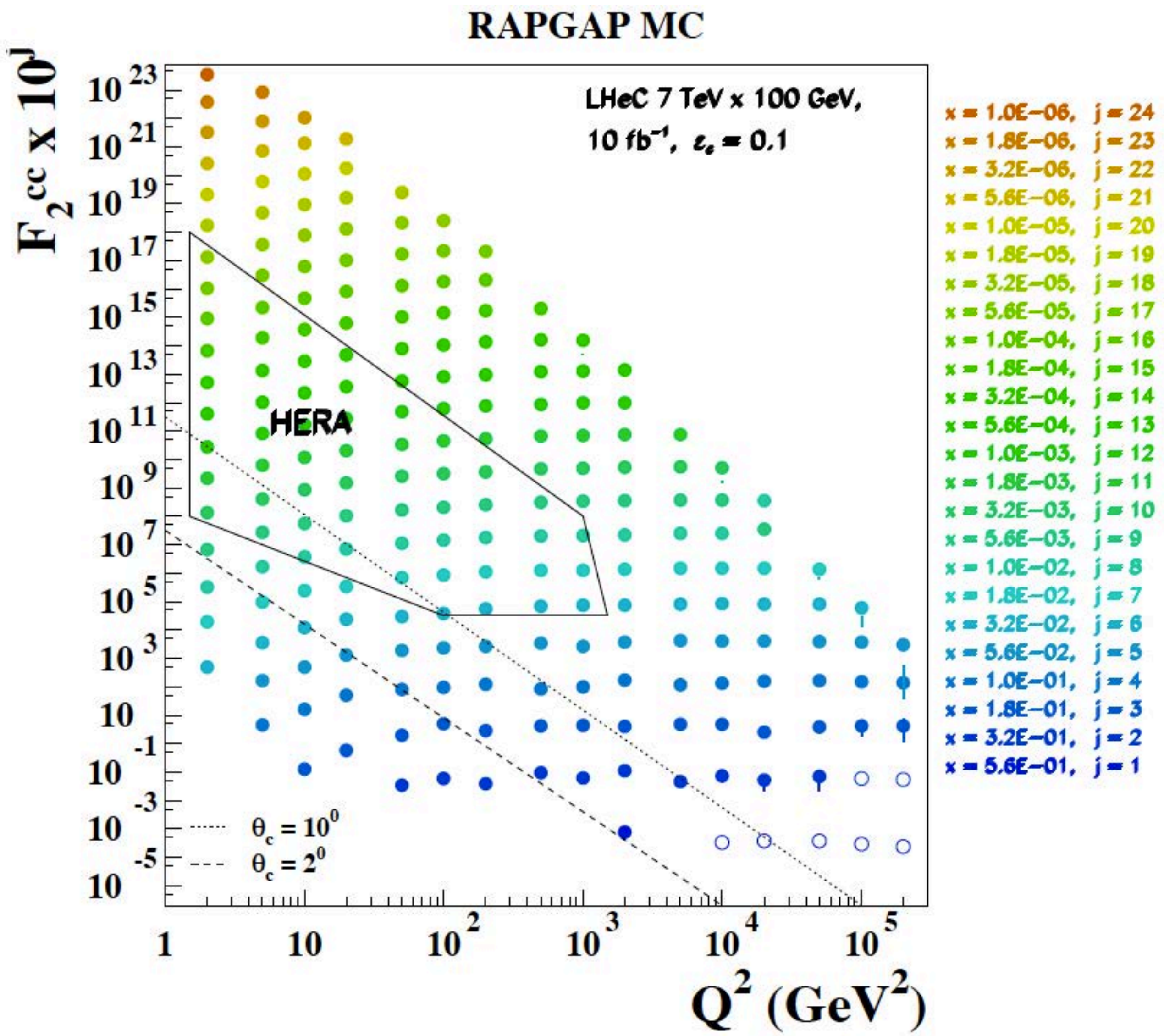
Studies also done with lowered proton energies. Maximum y for all beam energies can be high. Results from both simulations are similar.

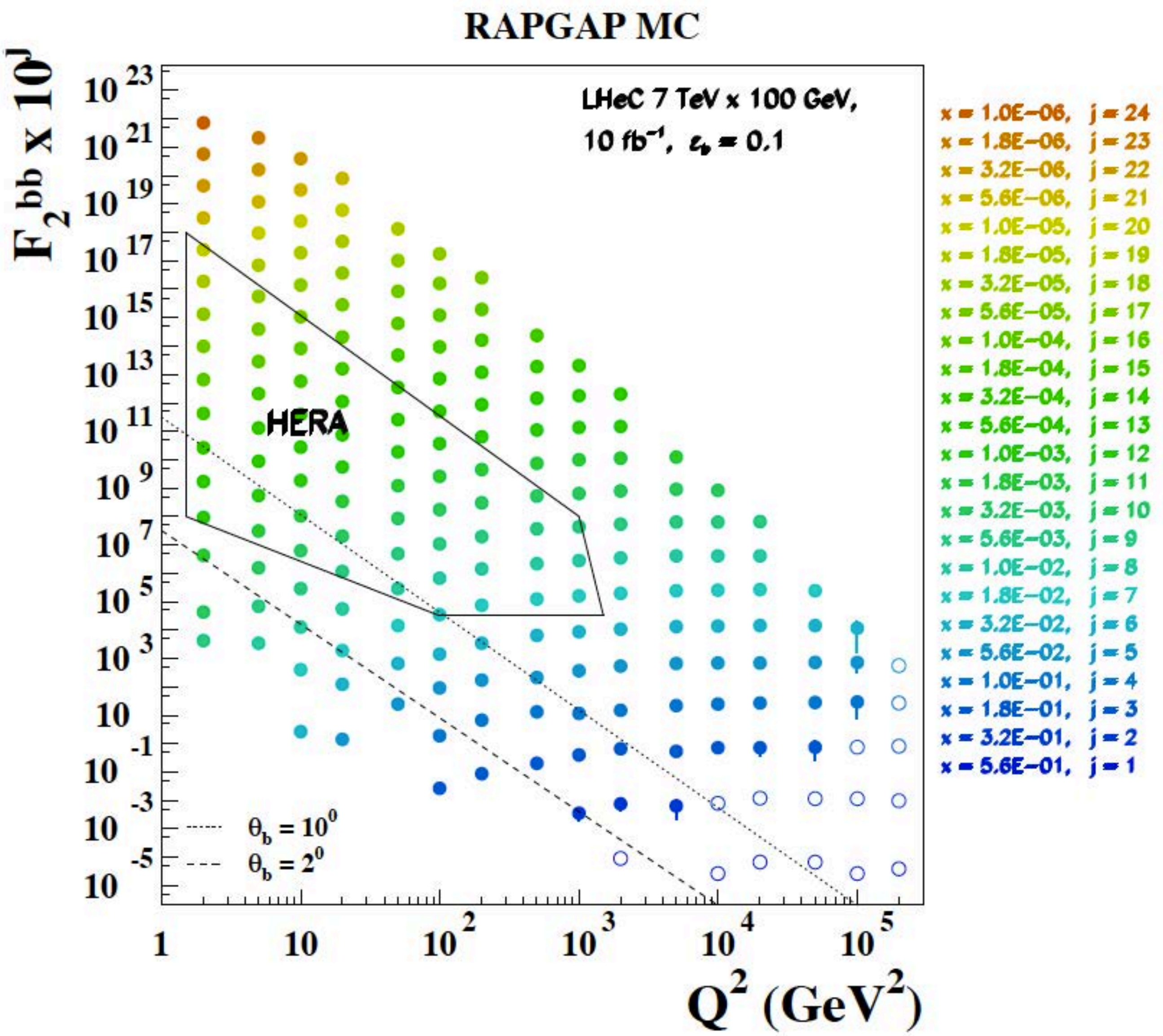


Heavy flavor in ep

Simulations with RAPGAP MC 3.1

Impressive extension of the phase space.
Both small and large x.

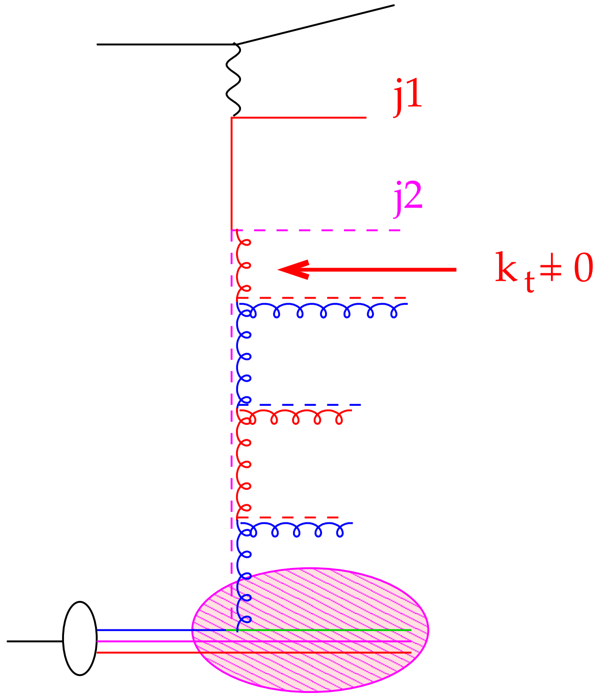


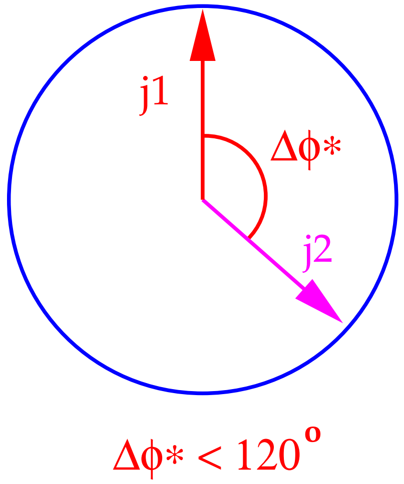


Crucial as a benchmark for the heavy flavor production in nuclei. Can test thoroughly the nuclear effects of in heavy quark production.

Dijets in ep

- Incoming gluon can have sizeable transverse momentum.
- Decorrelation of pairs of jets, which increases with decreasing value of x.
- Collinear approach typically produces narrow back-to-back configuration. Need to go to higher orders(NLO not sufficient).
- Similar process can be studied in eA, sensitivity to density effects.





$-1 < \eta_{\text{jet}} < 2.5$

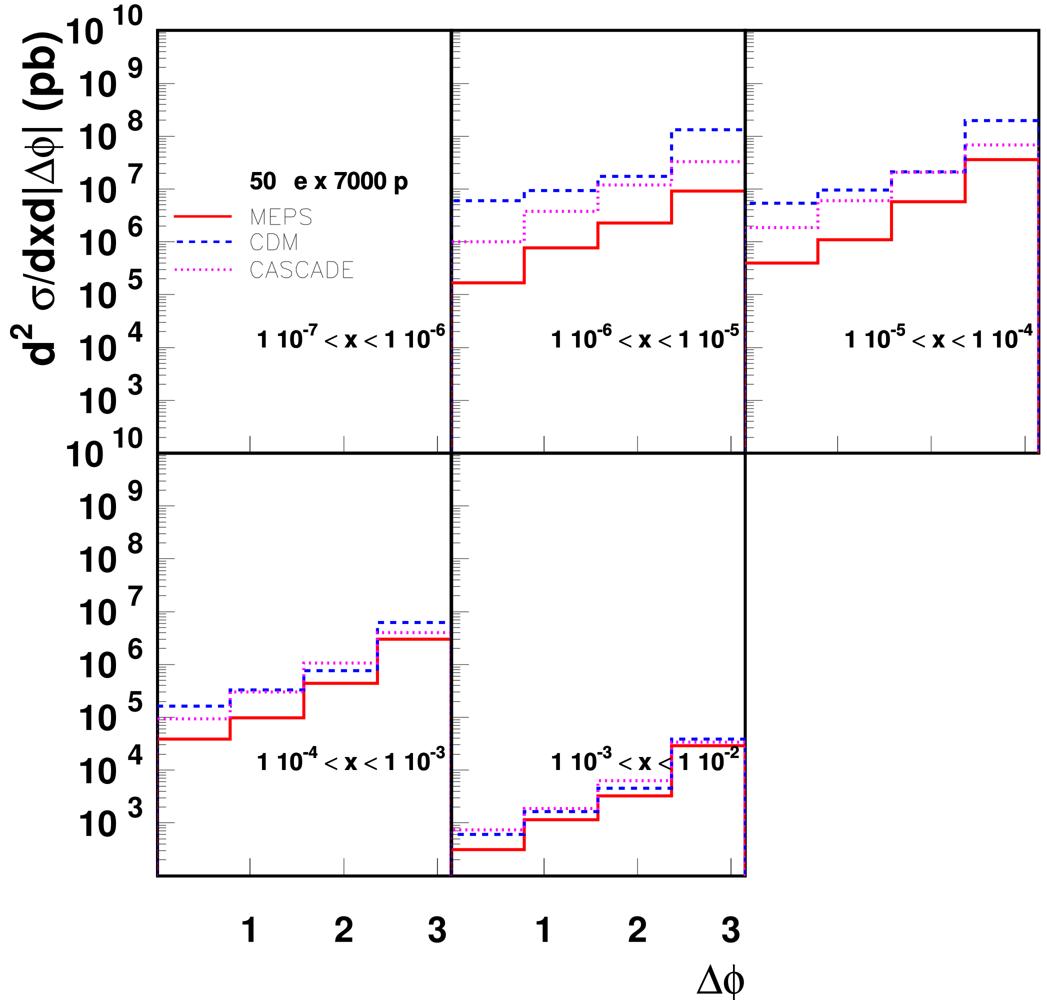
$0.1 < y < 0.6$

$E_{1T} > 7\ \text{GeV}$

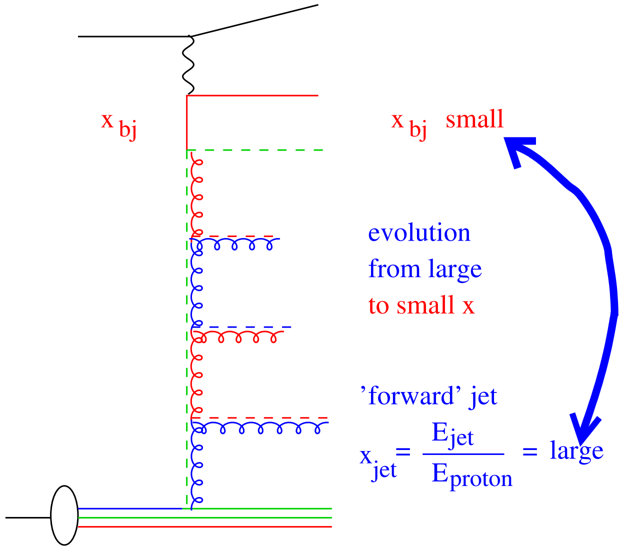
$Q^2 > 5\ \text{GeV}^2$

$E_{2T} > 5\ \text{GeV}$

- All simulations agree at large x.
- CDM, CASCADE give a flatter distribution at small x.



Forward jets



- Forward jet provides the second hard scale.
- By selecting it to be of the order of the photon virtuality, collinear configurations can be suppressed.
- Forward jet, large phase space for gluon emission.
- DGLAP typically underestimates the forward jet production.

Simulations for

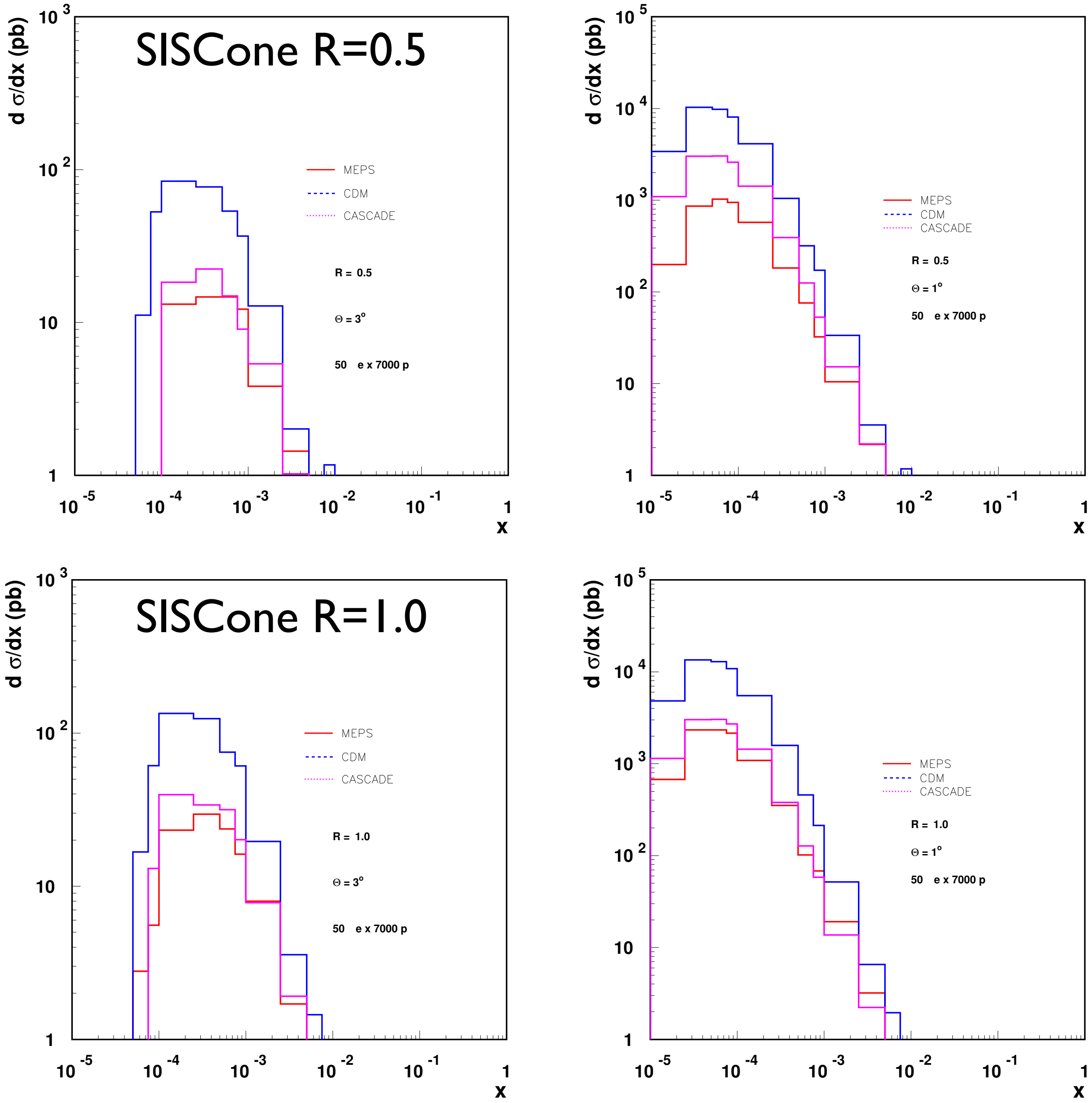
$\Theta > 3^o$ and $\Theta > 1^o$

Angular acceptance crucial for this measurement.

With $\Theta > 10^o$

all the signal for forward jets is lost.

Can explore also forward pions. Lower rates but no dependencies on the jet algorithms. Non-perturbative hadronisation effects included effectively in the fragmentation functions.



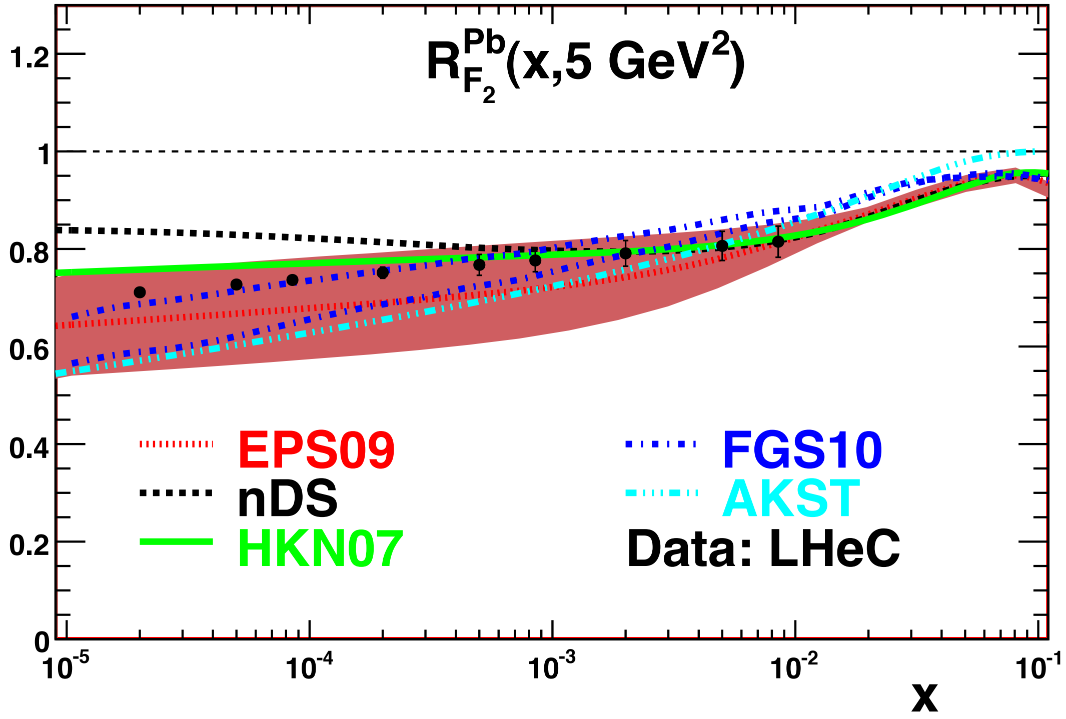
Nuclear structure functions at LHeC

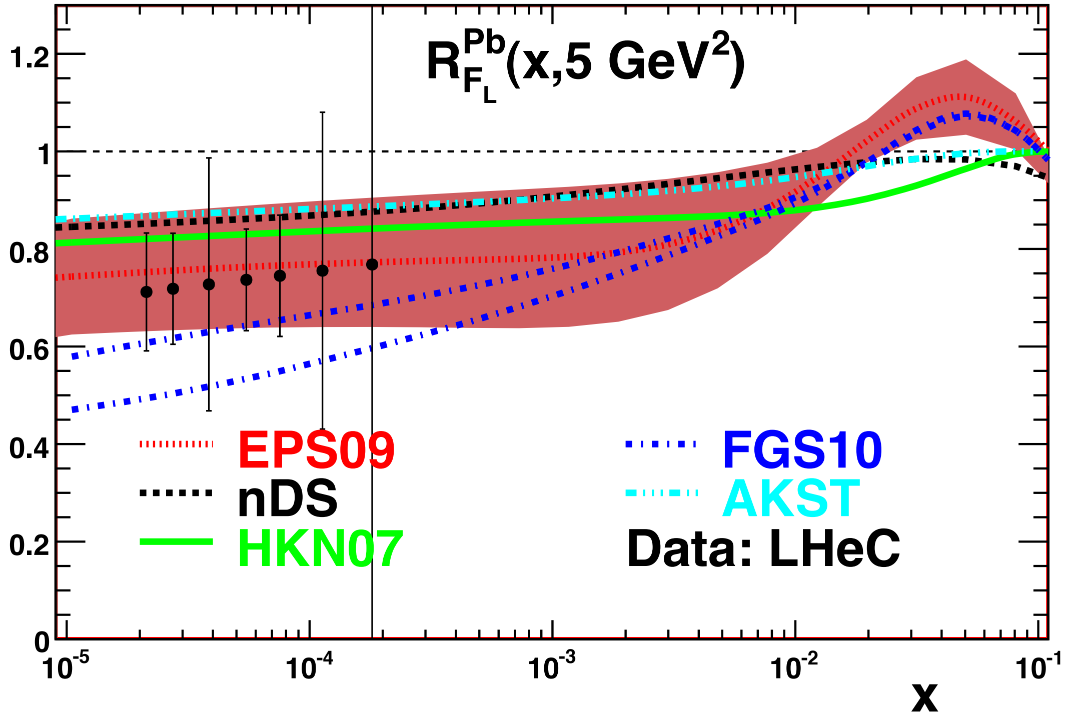
Nuclear ratio for structure function or a parton density:

$$R_f^A(x,Q^2) = \frac{f^A(x,Q^2)}{A \times f^N(x,Q^2)}$$

Nuclear effects $R^A \neq 1$

LHeC potential: precisely measure partonic structure of the nuclei at small x.

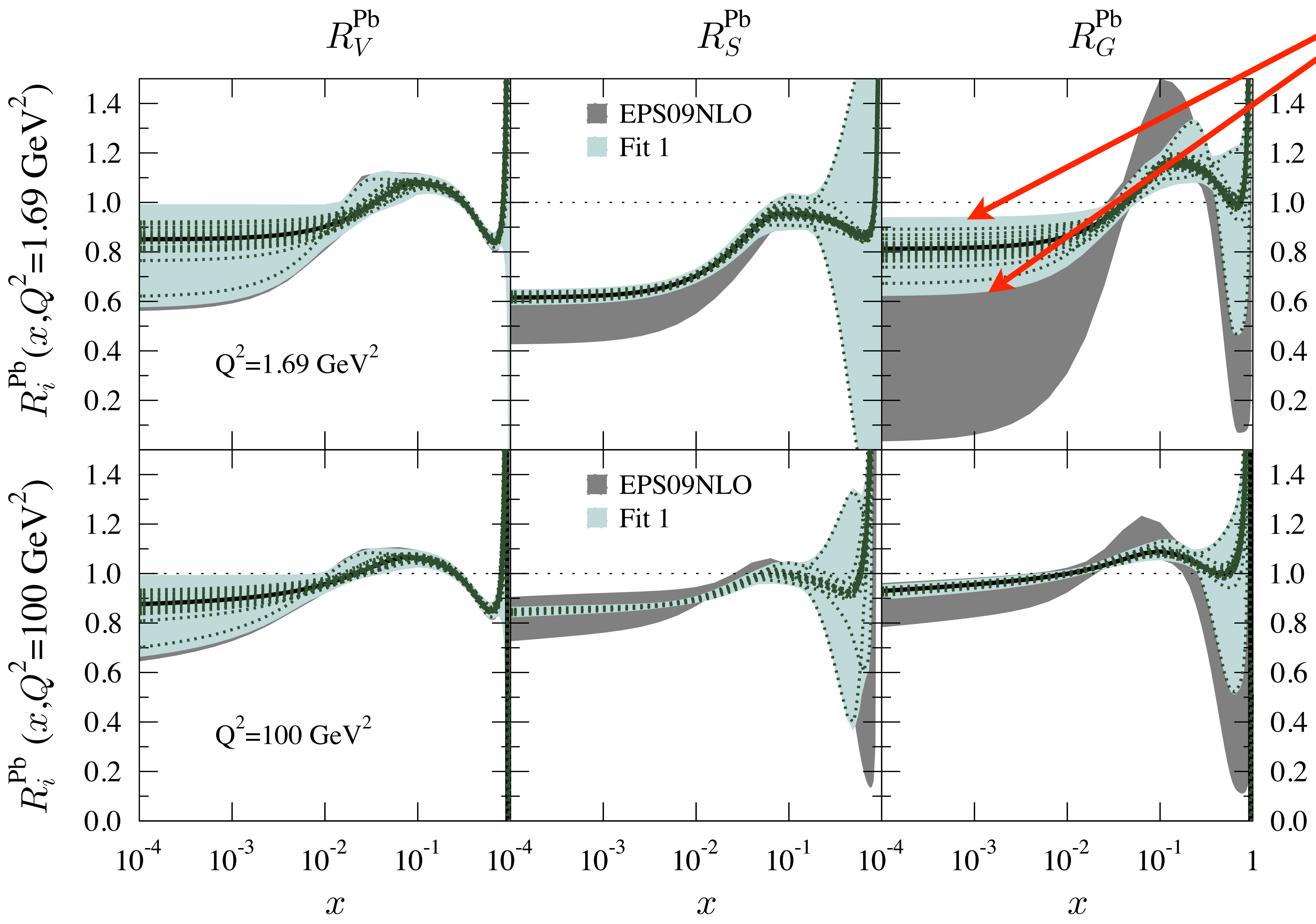




Nuclear structure functions measured with very high accuracy.

Nuclear parton distributions at LHeC

Global NLO fit of nuclear PDFs with the LHeC pseudodata included



Much smaller uncertainties.

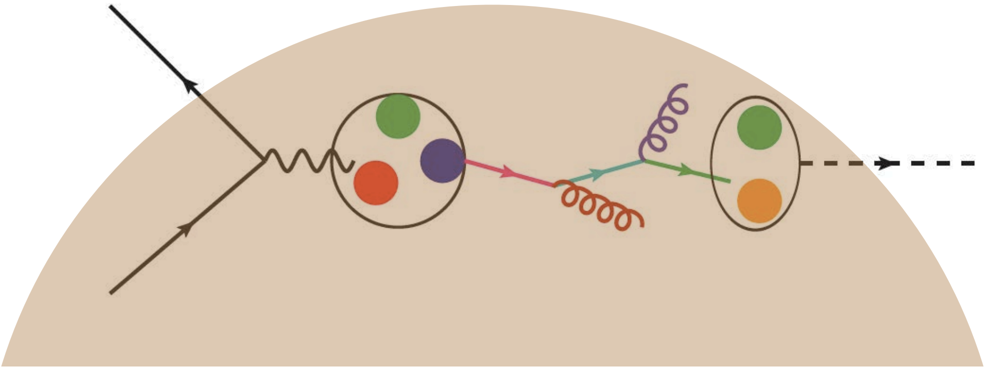
Very large constraint on the low x gluons and sea quarks with the LHeC pseudodata .

Radiation and Hadronization

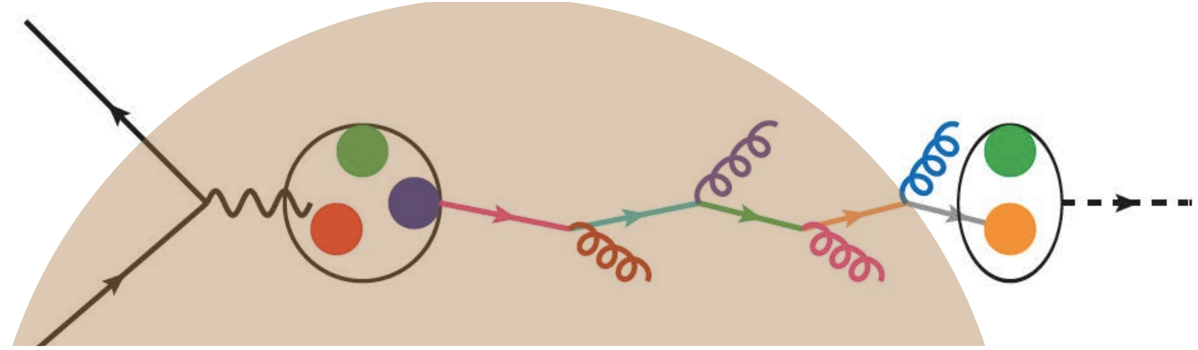
- LHeC can provide information on radiation and hadronization.
- Large lever arm in energy allows probing different timescales.
- Important for HI collisions .

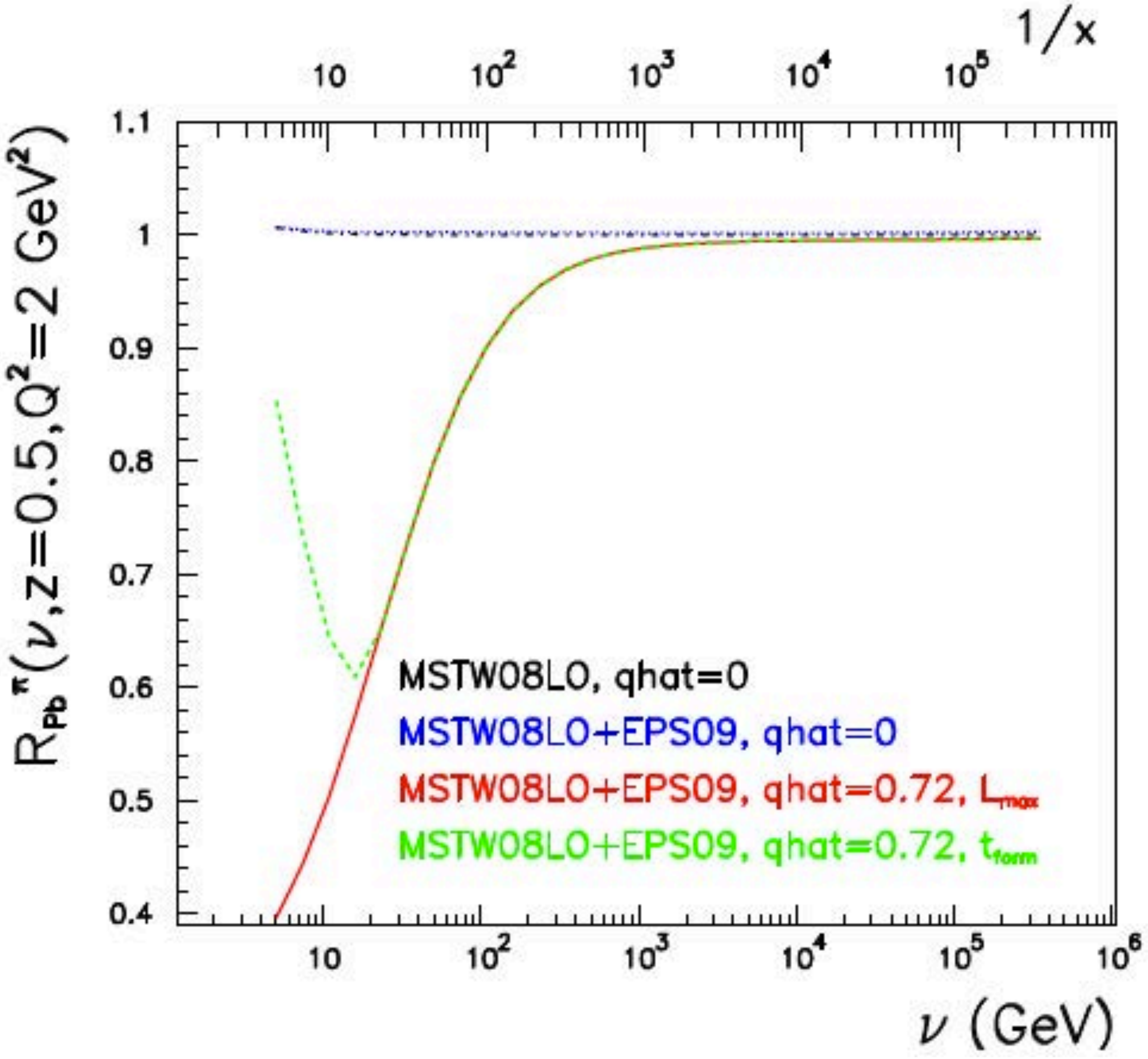
$$R_A^k(\nu, z, Q^2) = \frac{1}{N_A^e}\frac{dN_A^k}{d\nu dz} \Bigg/ \frac{1}{N_p^e}\frac{dN_p^k}{d\nu dz}$$

Low energy: hadronization inside

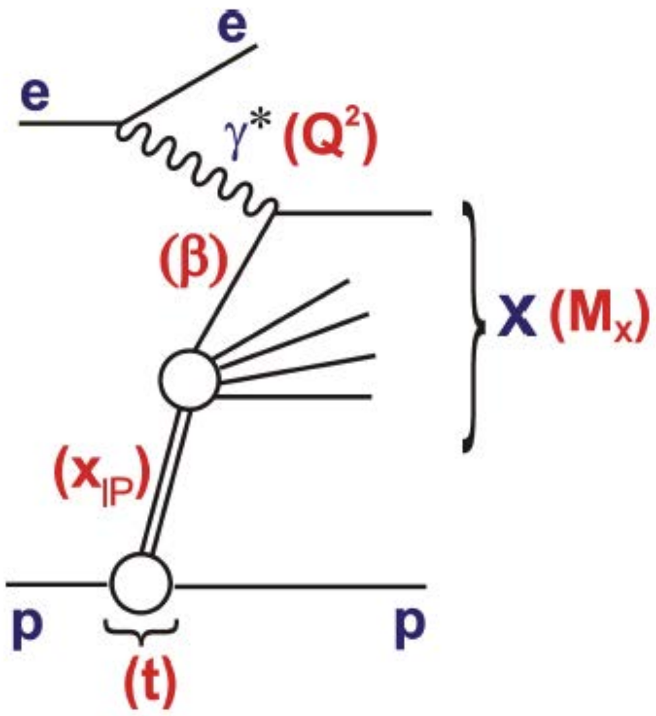


High energy: partonic evolution altered in nuclear medium





Diffraction



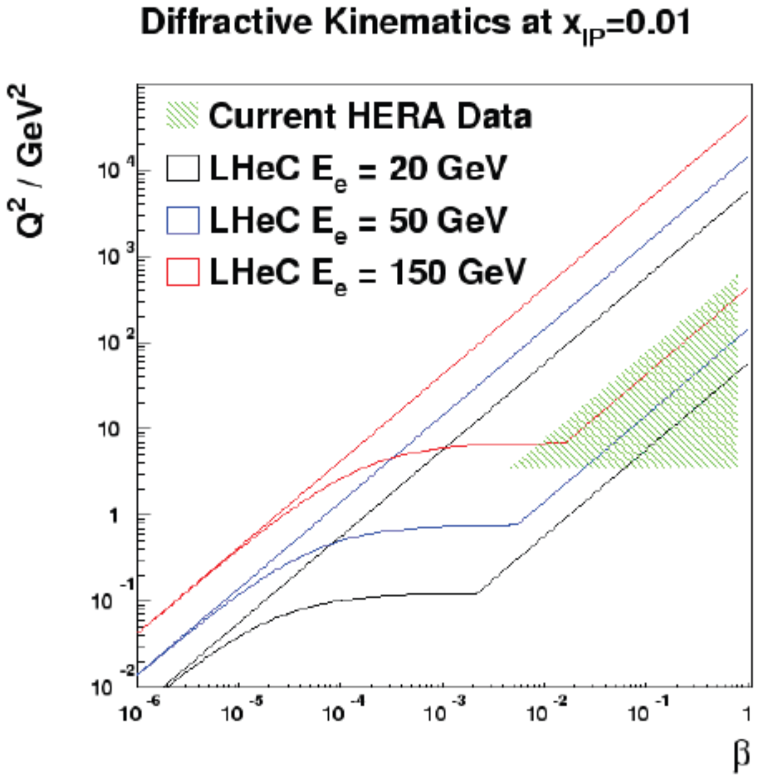
$$x_{IP} = \frac{Q^2 + M_X^2 - t}{Q^2 + W^2}$$

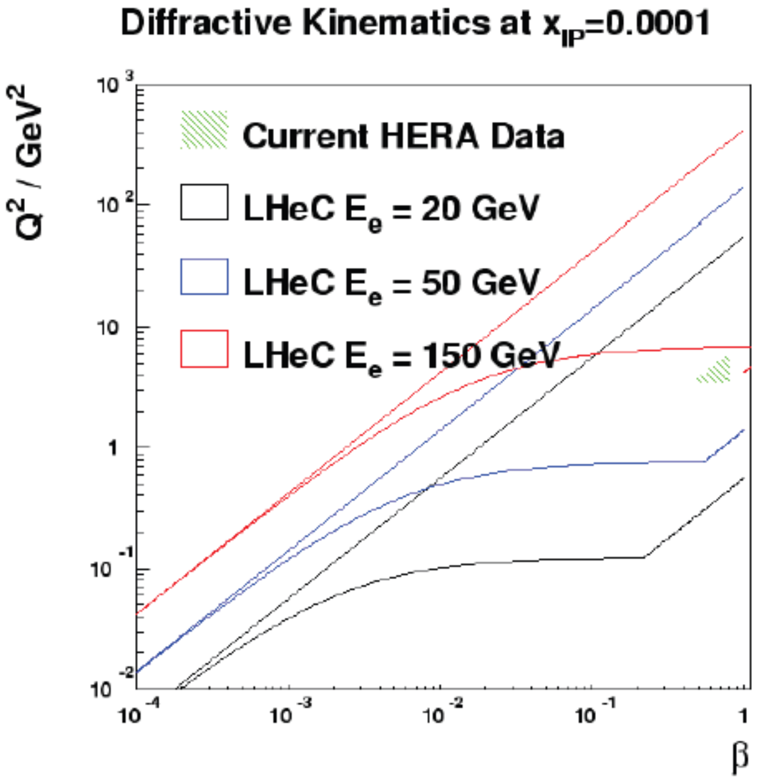
momentum fraction of the Pomeron w.r.t hadron

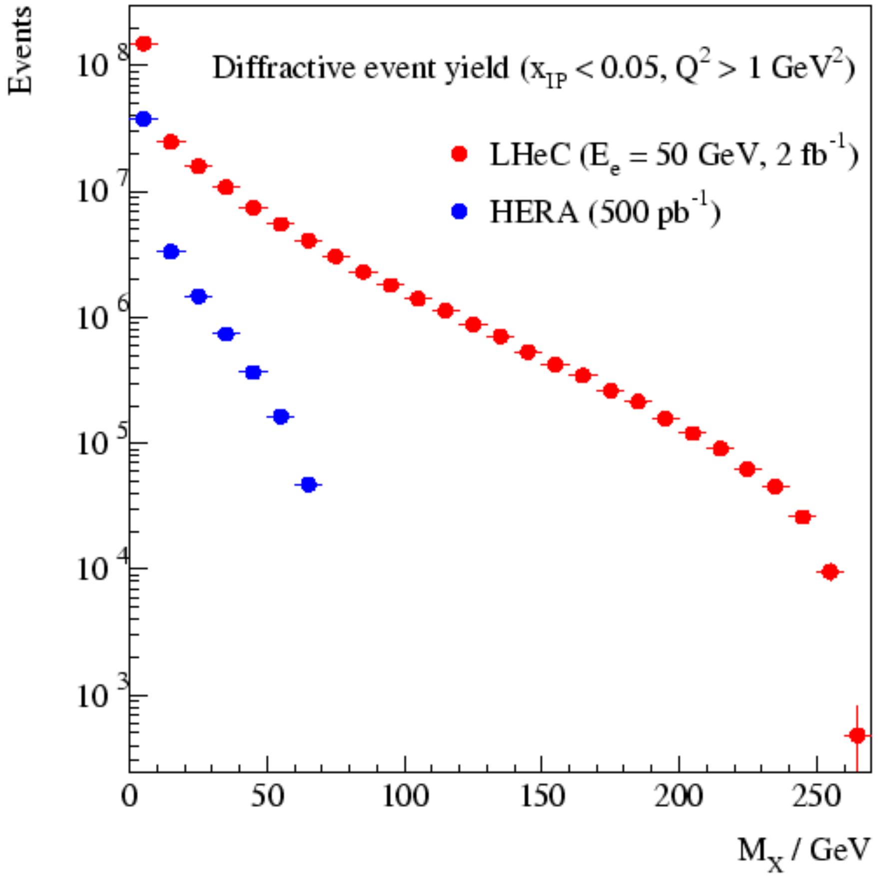
$$\beta = \frac{Q^2}{Q^2 + M_X^2 - t}$$

momentum fraction of parton w.r.t Pomeron

$$x_{Bj} = x_{IP}\beta$$



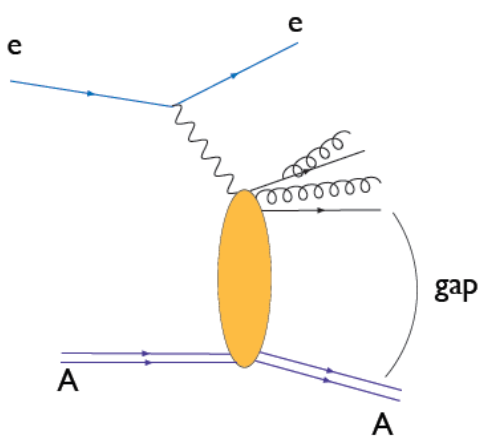




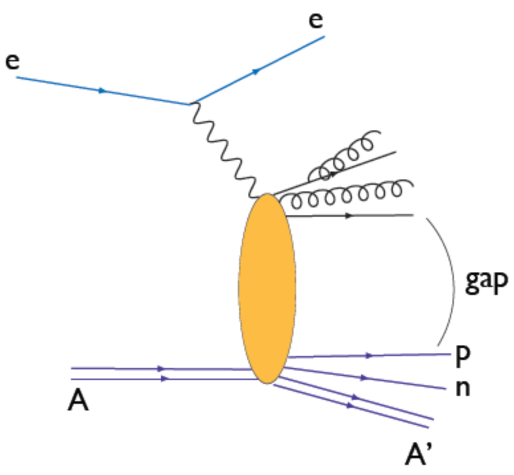
Methods: Leading proton tagging, large rapidity gap selection

New domain of diffractive masses M_X can include W/Z/beauty

Inclusive diffraction in eA

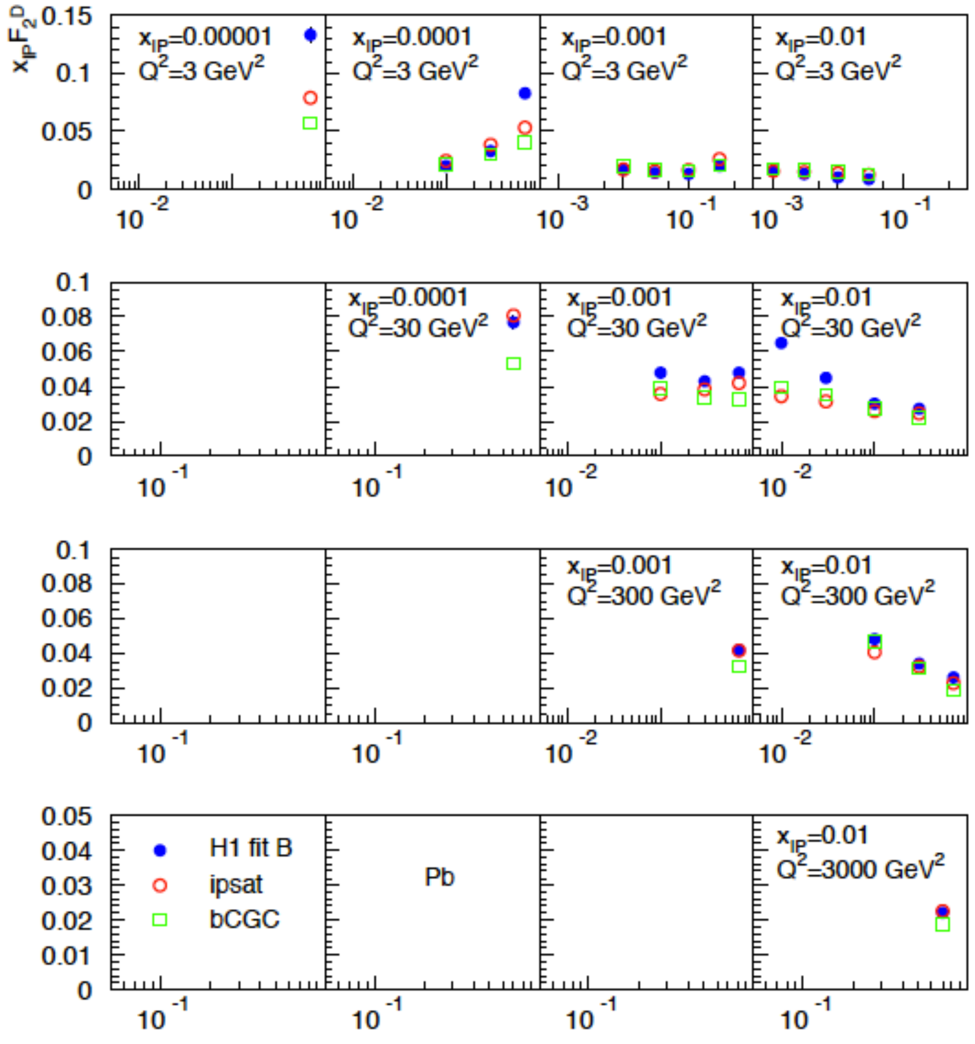


coherent

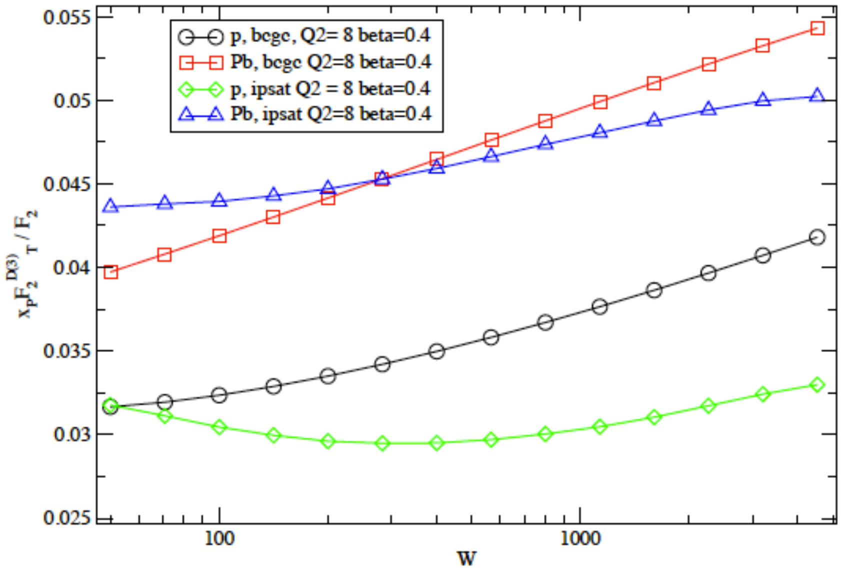


incoherent

Diffractive structure function for Pb



Diffractive to inclusive ratio for protons and Pb

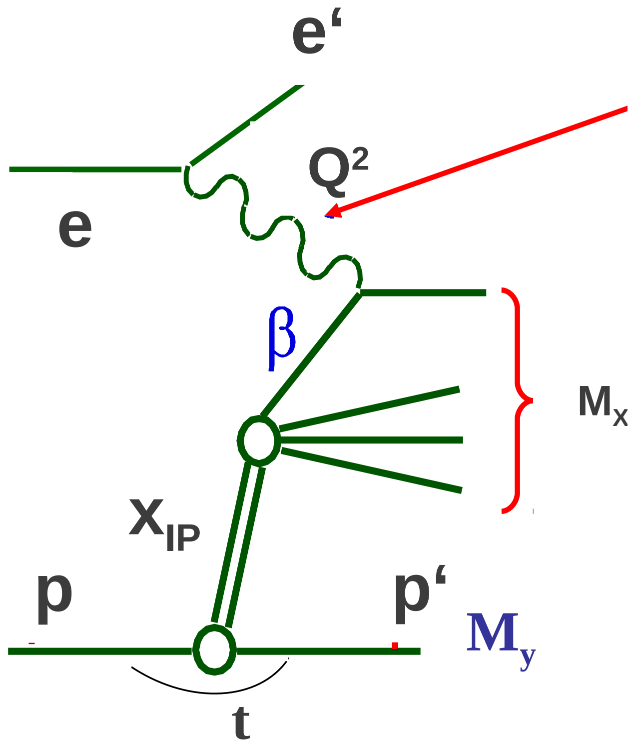


Enhanced diffraction in the nuclear case

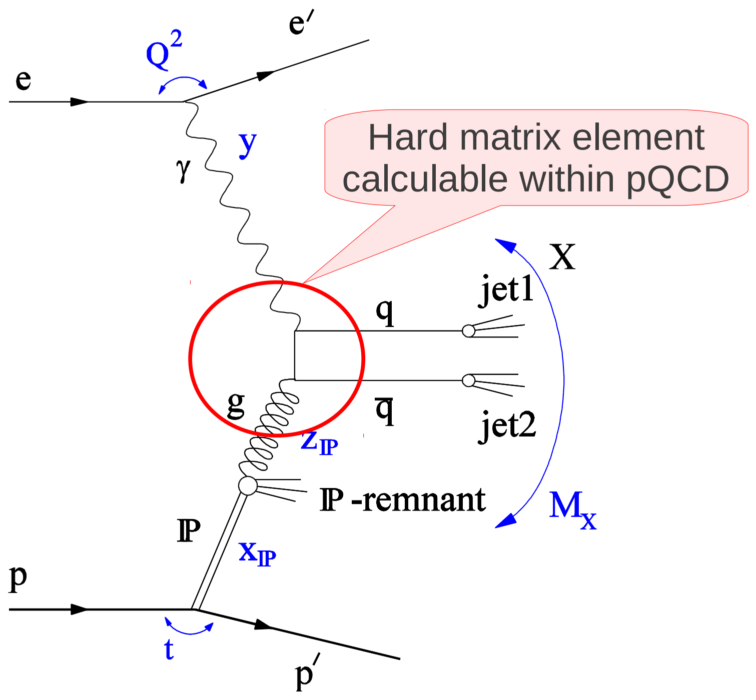
Study of diffractive dijets, heavy quarks for the factorization tests

Factorization in diffraction

Inclusive diffraction



Diffractive dijets



Hard matrix element calculable within pQCD

QCD factorization holds for inclusive and exclusive processes if:

- photon is point-like (Q^2 is high enough)
- higher twist corrections are negligible (problems for small Q^2 around $\beta \simeq 1$)
  QCD factorization theoretically proven for DIS (Collins 1998)

$$d\sigma^D(\gamma p \to Xp) = \sum_{parton_i} f_i^D(\beta, Q^{2,} x_{IP}, t) * d\hat{\sigma}^{\gamma i}(x, Q^2)$$

f_i^D DPDFs, obeys DGLAP evolution, process independent

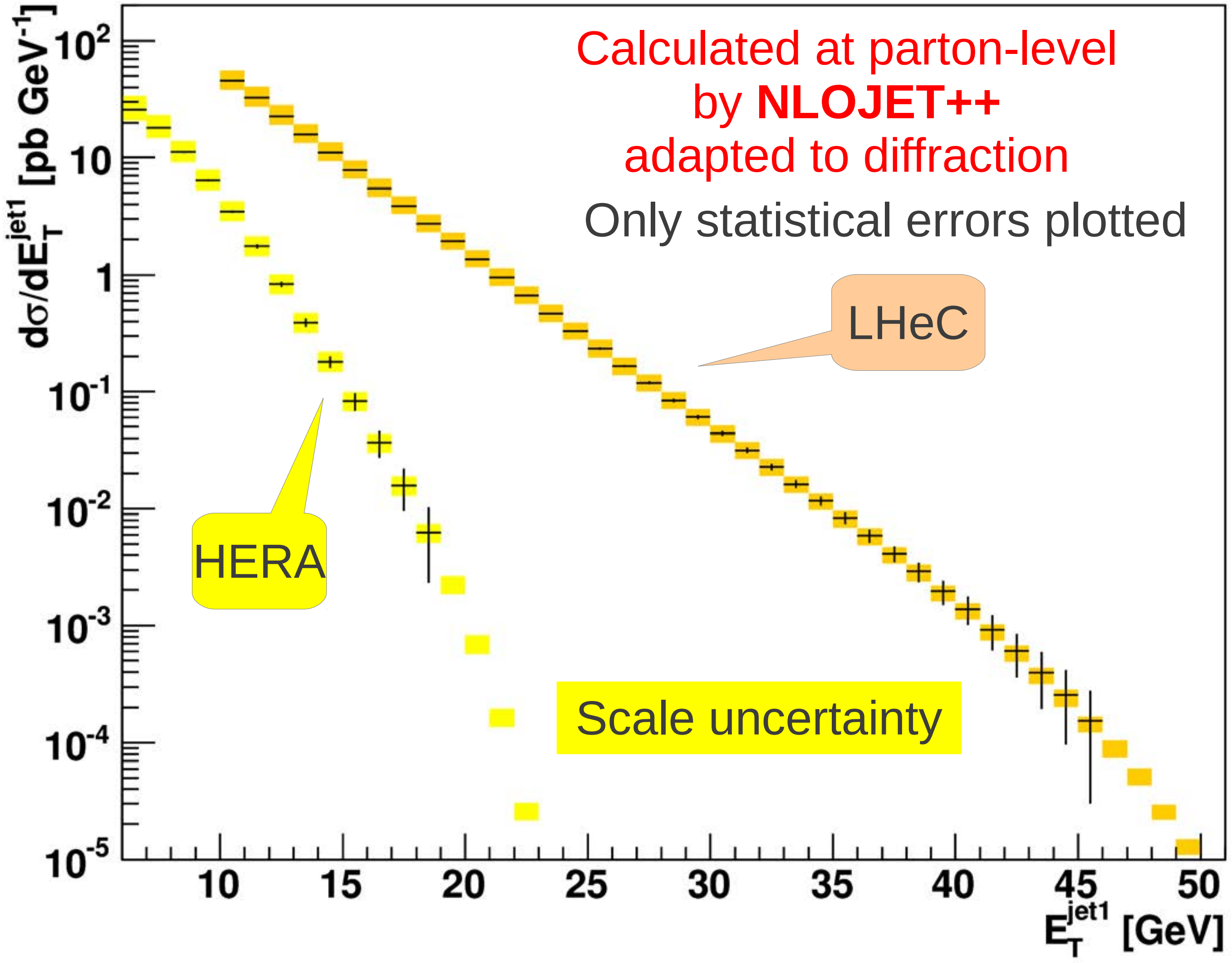
$d\hat{\sigma}^{\gamma i}$ Process dependent partonic x-section, calculable within pQCD

Talk by Radek Zlebcik in Chavannes-de-Bogis

DIS Dijets HERA vs LHeC Comparison of Synthetic Data

- Higher CMS energy makes higher scales accessible

HERA	LHeC
$E_T^{\text{jet1}} \sim 15\,\text{GeV}$	$E_T^{\text{jet1}} \sim 40\,\text{GeV}$



Calculated at parton-level by **NLOJET++** adapted to diffraction

Only statistical errors plotted

Scale uncertainty

920 + 27.5 HERA ($400\,\text{pb}^{-1}$)

$$Q^2 > 4\,\text{GeV}^2 \wedge 0.1 < y < 0.7$$
$$x_{IP} < 0.03 \wedge |t| < 1\,\text{GeV}^2$$
$$M_Y < 1.6\,\text{GeV}$$
$$E_T^{\text{jet1}} > 6\,\text{GeV}$$
$$E_T^{\text{jet2}} > 4\,\text{GeV}$$
$$-1 < \eta^{\text{jets}} < 2$$

7000 + 60 LHeC ($10\,\text{fb}^{-1}$)

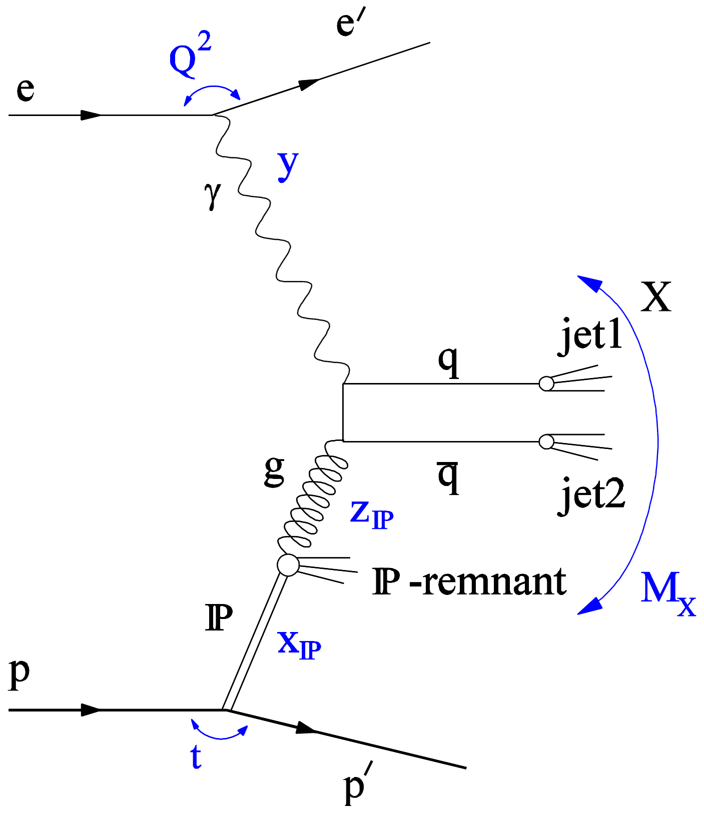
$$Q^2 > 2\,\text{GeV}^2 \wedge 0.1 < y < 0.7$$
$$x_{IP} < 0.01 \wedge |t| < 1\,\text{GeV}^2$$
$$M_Y < 1.6\,\text{GeV}$$
$$E_T^{\text{jet1}} > 10\,\text{GeV}$$
$$E_T^{\text{jet2}} > 6.5\,\text{GeV}$$
$$-3 < \eta^{\text{jets}} < 3$$

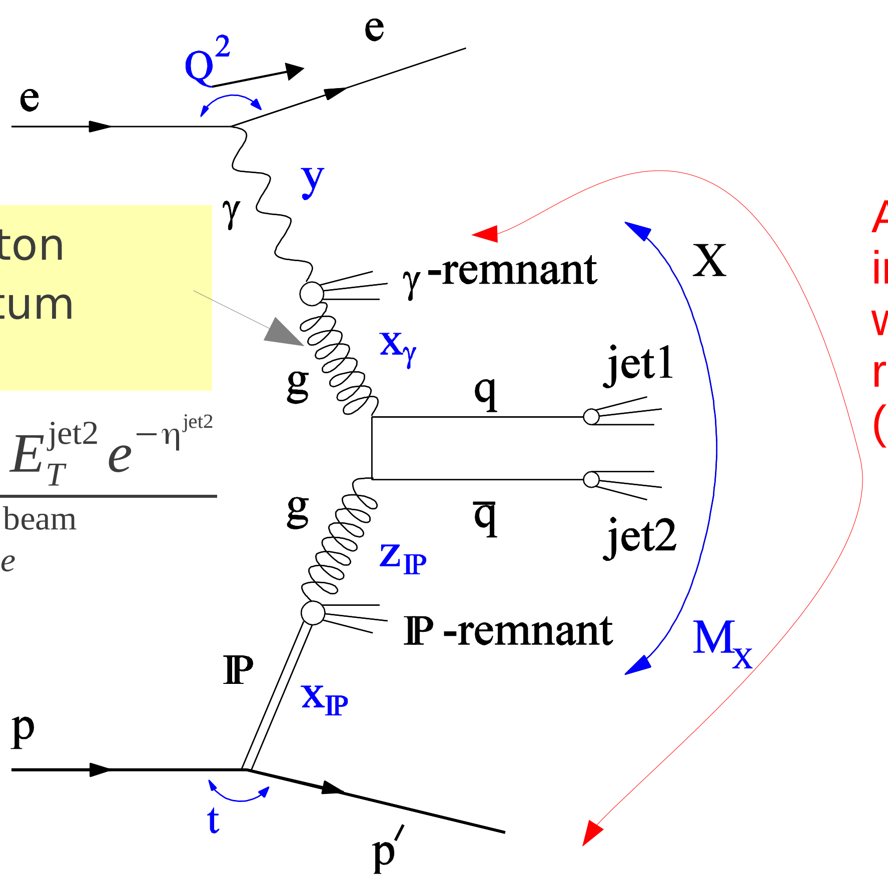
$$Q^2 > 2\,\text{GeV}^2 \rightarrow \theta_{el} < 178.5°$$
$$Q^2 > 4\,\text{GeV}^2 \rightarrow \theta_{el} < 176.5°$$

Diffractive Dijet Photoproduction

Direct
No photon remnant
$x_\gamma = 1$ (at parton-level)
Dominant for high Q^2
(near DIS region)

Resolved
photon remnant
$x_\gamma < 1$
Dominant for low Q^2, γ-PDF introduced:





x_γ – photon momentum fraction

$$x_\gamma = \frac{E_T^{jet1} e^{-\eta^{jet1}} + E_T^{jet2} e^{-\eta^{jet2}}}{2y\, E_e^{beam}}$$

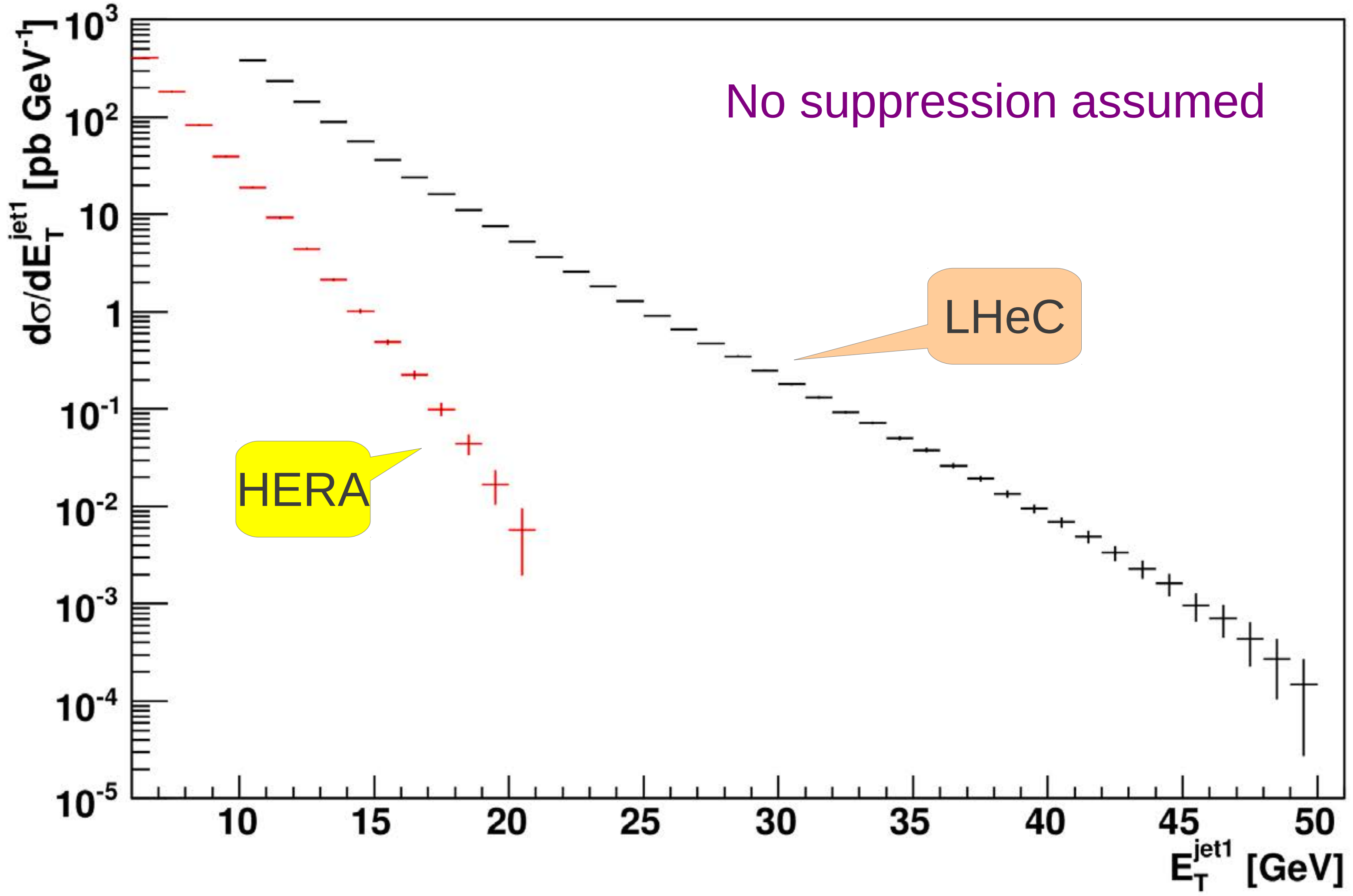
Additional interactions which spoil rap. Gap? (like in pp)

PHP Dijets HERA vs LHeC

- Due to much higher E_T^{jet} jets at LHeC is LHeC better tool to investigate possible factorisation breaking

Calculated at parton-level by **Frixione NLO** adapted to diffraction

HERA	LHeC
$E_T^{\text{jet1}} \sim 17\,\text{GeV}$	$E_T^{\text{jet1}} \sim 42\,\text{GeV}$



No suppression assumed

Only statistical errors of synthetic data depicted
No acceptance and detector smearing effects take into account

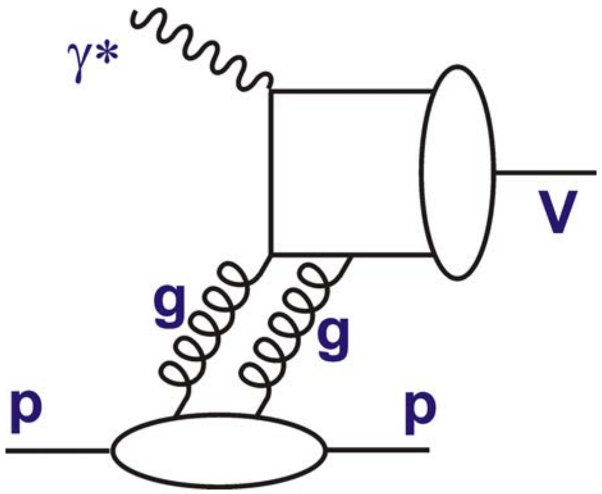
920 + 27.5 HERA $(400\,\text{pb}^{-1})$

$$Q^2 < 2\,\text{GeV}^2 \wedge 0.2 < y < 0.8$$
$$x_{IP} < 0.03 \wedge |t| < 1\,\text{GeV}^2$$
$$M_Y < 1.6\,\text{GeV}$$
$$E_T^{\text{jet1}} > 6\,\text{GeV}$$
$$E_T^{\text{jet2}} > 4\,\text{GeV}$$
$$-1 < \eta^{\text{jets}} < 2$$

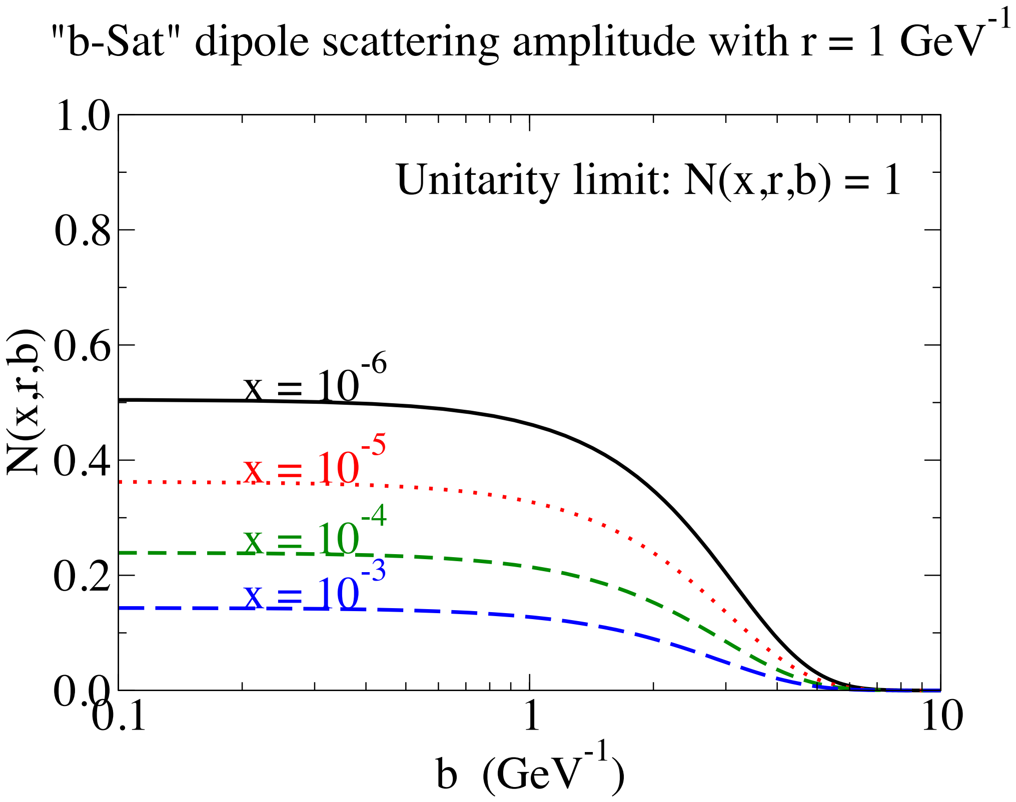
7000 + 60 LHeC $(10\,\text{fb}^{-1})$

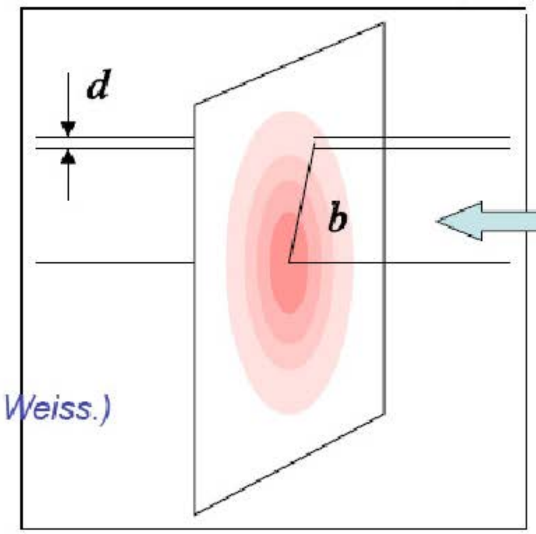
$$Q^2 < 2\,\text{GeV}^2 \wedge 0.2 < y < 0.8$$
$$x_{IP} < 0.01 \wedge |t| < 1\,\text{GeV}^2$$
$$M_Y < 1.6\,\text{GeV}$$
$$E_T^{\text{jet1}} > 10\,\text{GeV}$$
$$E_T^{\text{jet2}} > 6.5\,\text{GeV}$$
$$-3 < \eta^{\text{jets}} < 3$$

Exclusive diffraction



- Exclusive diffractive production of VM is an excellent process for extracting the dipole amplitude and GPDs
- Suitable process for estimating the 'blackness' of the interaction.
- t-dependence provides an information about the impact parameter profile of the amplitude.





(figure from C. Weiss.)

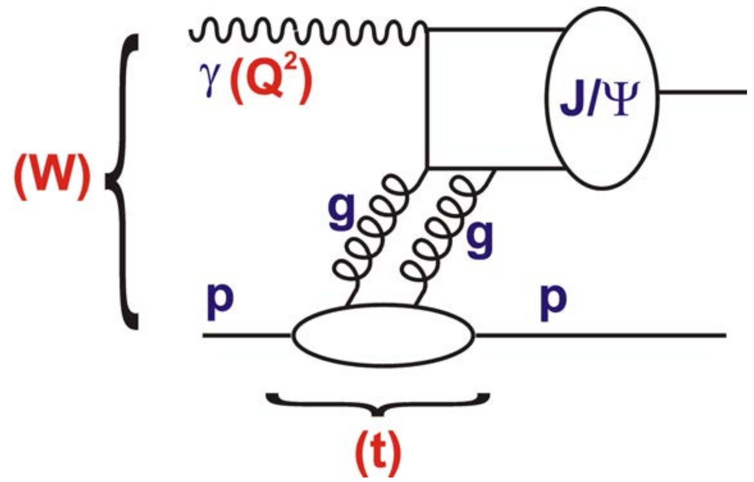
Central black region growing with decrease of x.

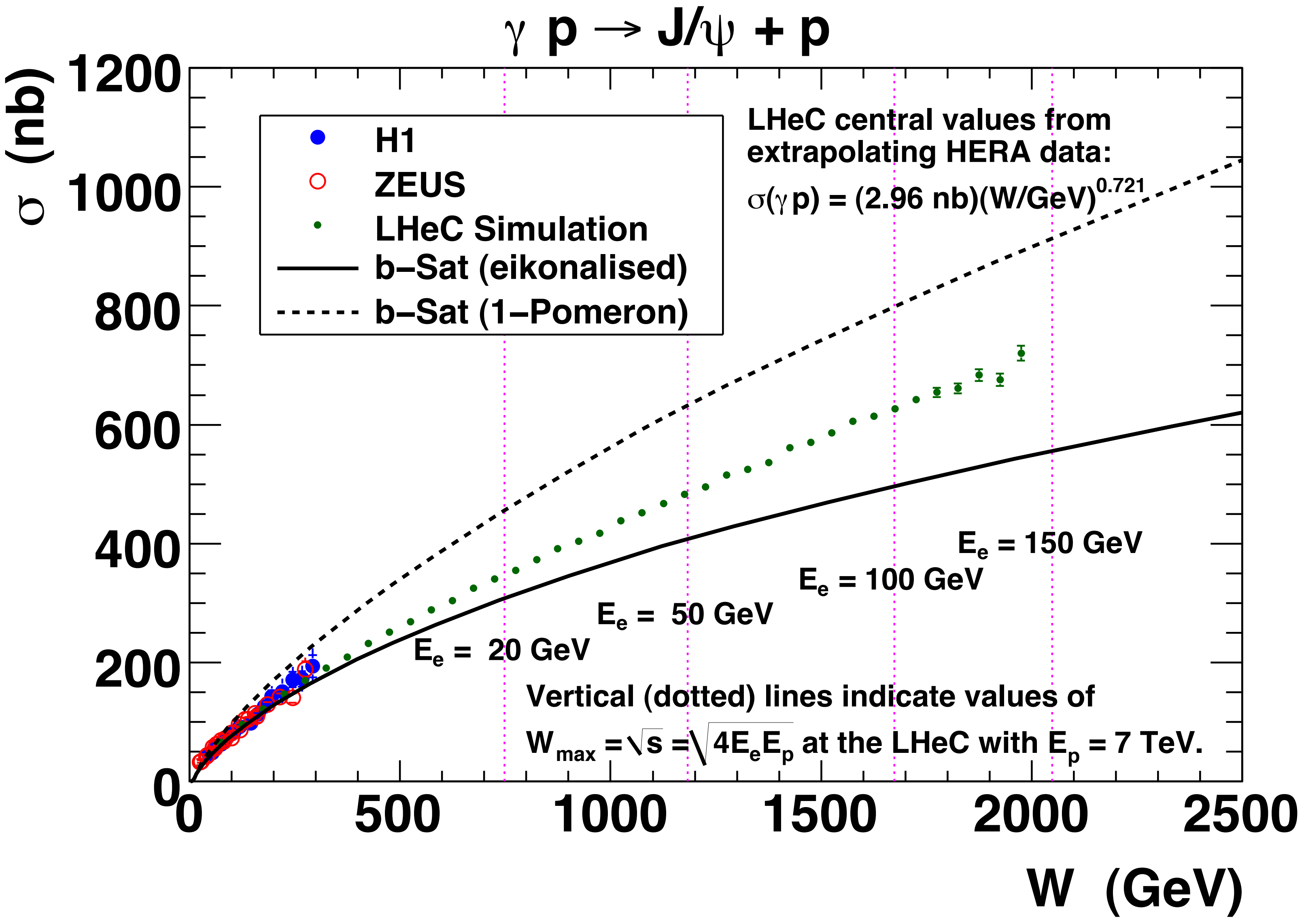
Large momentum transfer t probes small impact parameter where the density of interaction region is most dense.

Exclusive diffraction: predictions

$$\sigma^{\gamma p\rightarrow J/\Psi+p}(W)$$

- b-Sat dipole model (Golec-Biernat, Wuesthoff, Bartels, Motyka, Kowalski, Watt)
- eikonalised: with saturation
- 1-Pomeron: no saturation





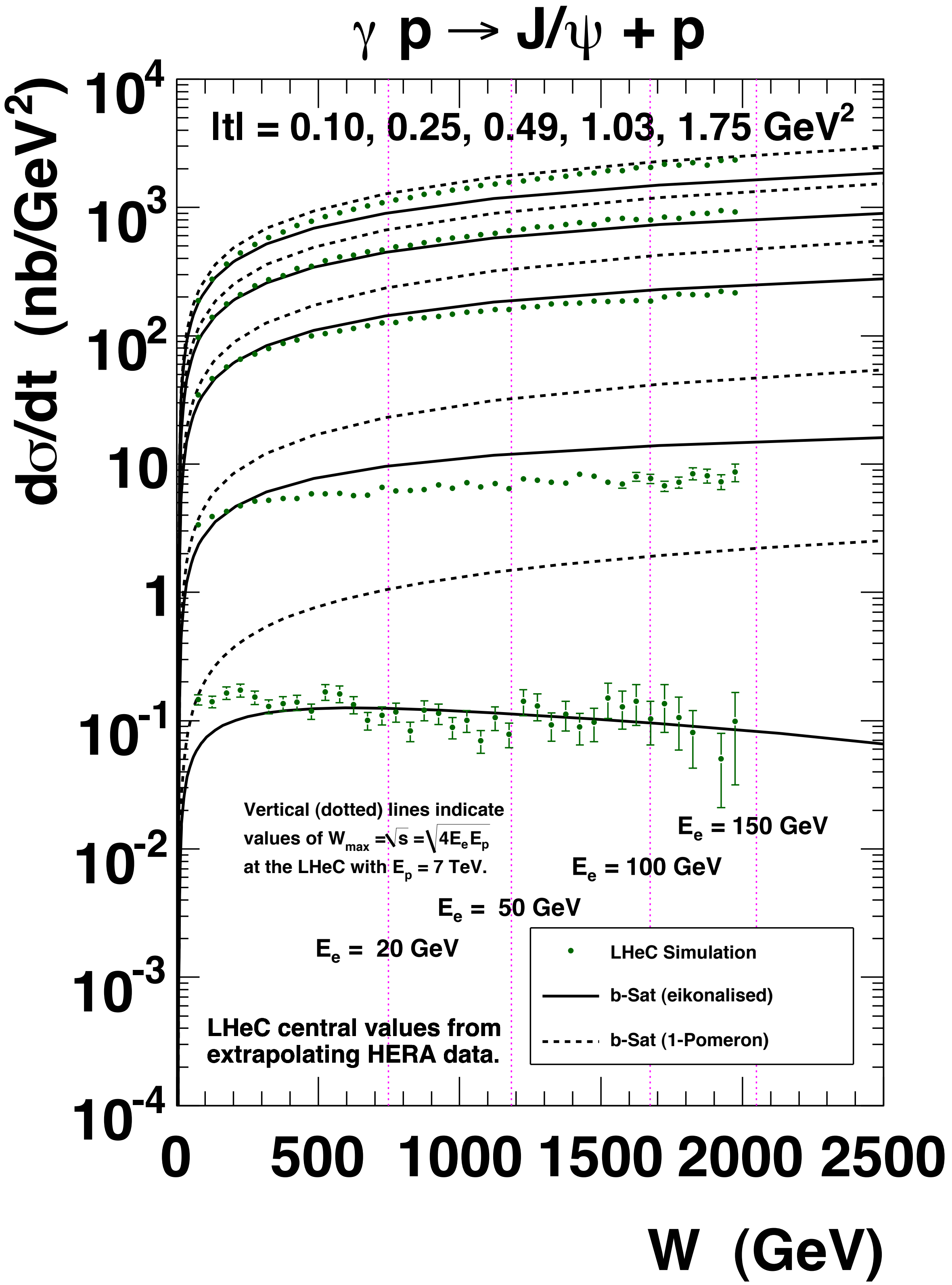
Large effects even for the t-integrated observable.

Different W behavior depending whether saturation is included or not.

Simulated data are from extrapolated fit to HERA data

LHeC can distinguish between the different scenarios.

Exclusive diffraction: t-dependence

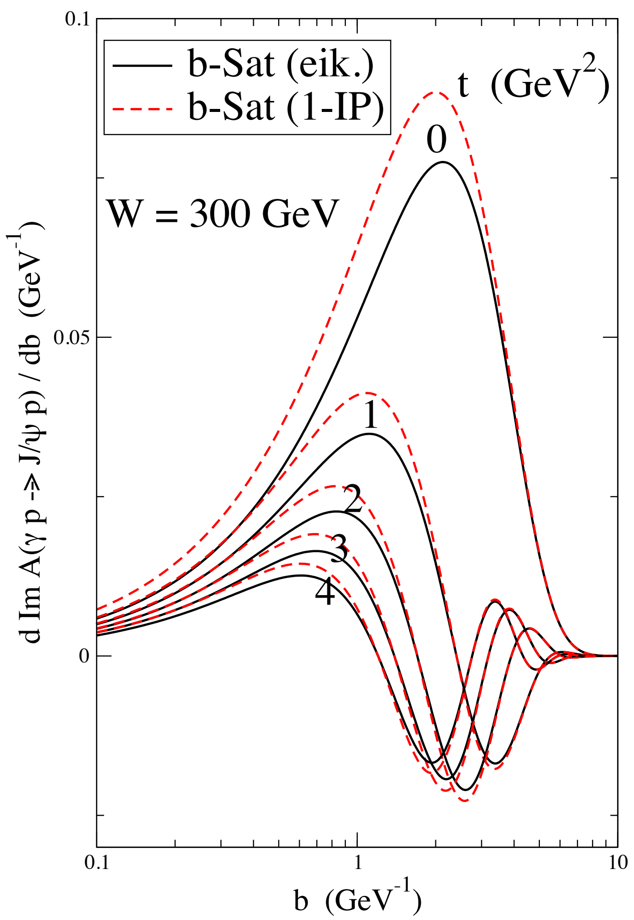


Photoproduction in bins of W and t.

Already for small values of t and smallest energies large discrepancies between the models. LHeC can discriminate.

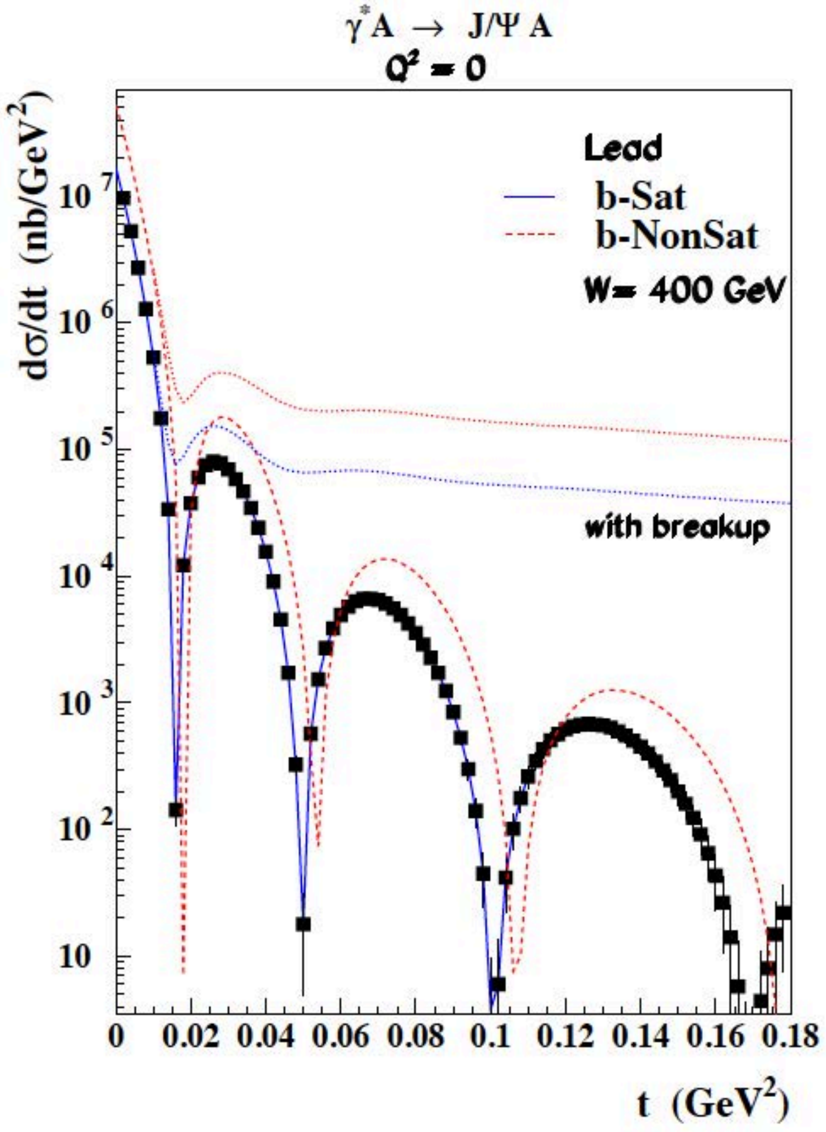
Large values of t : increased sensitivity to small impact parameters.

Amplitude as a function of the impact parameter.

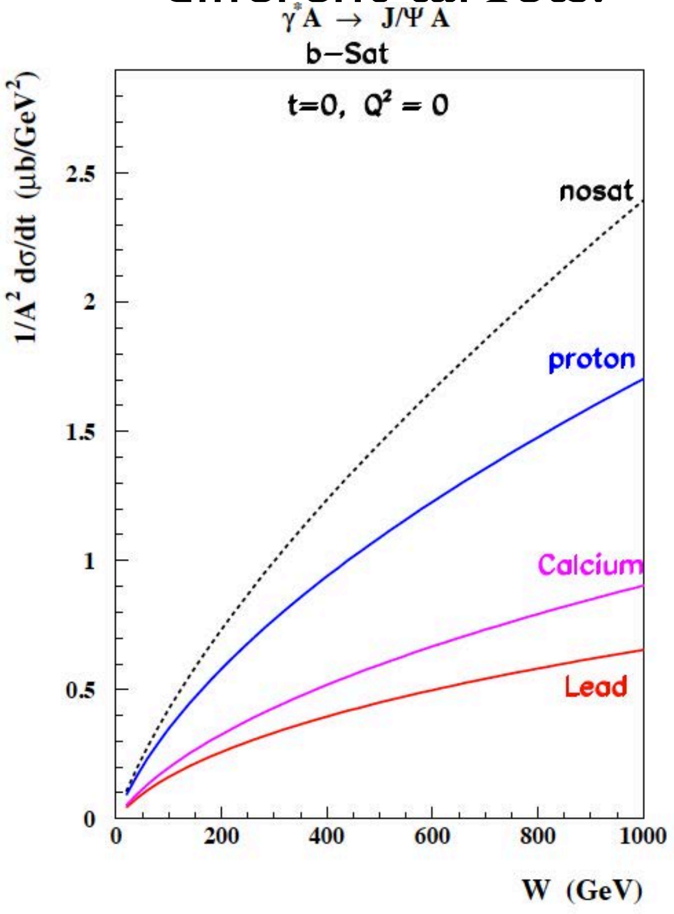


Exclusive diffraction on nuclei

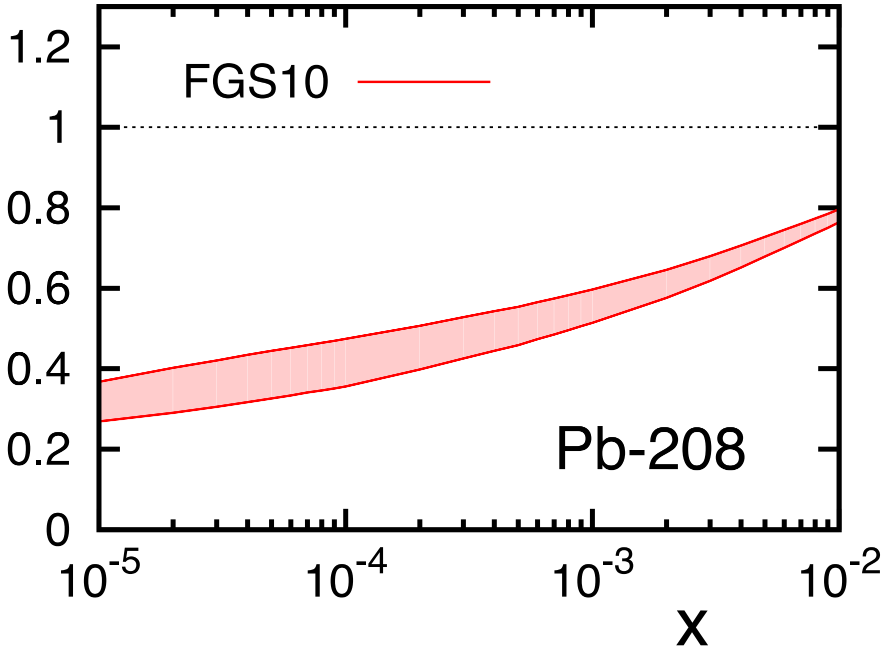
Possibility of using the same principle to learn about the gluon distribution in the nucleus.
Possible nuclear resonances at small t?



Energy dependence for different targets.



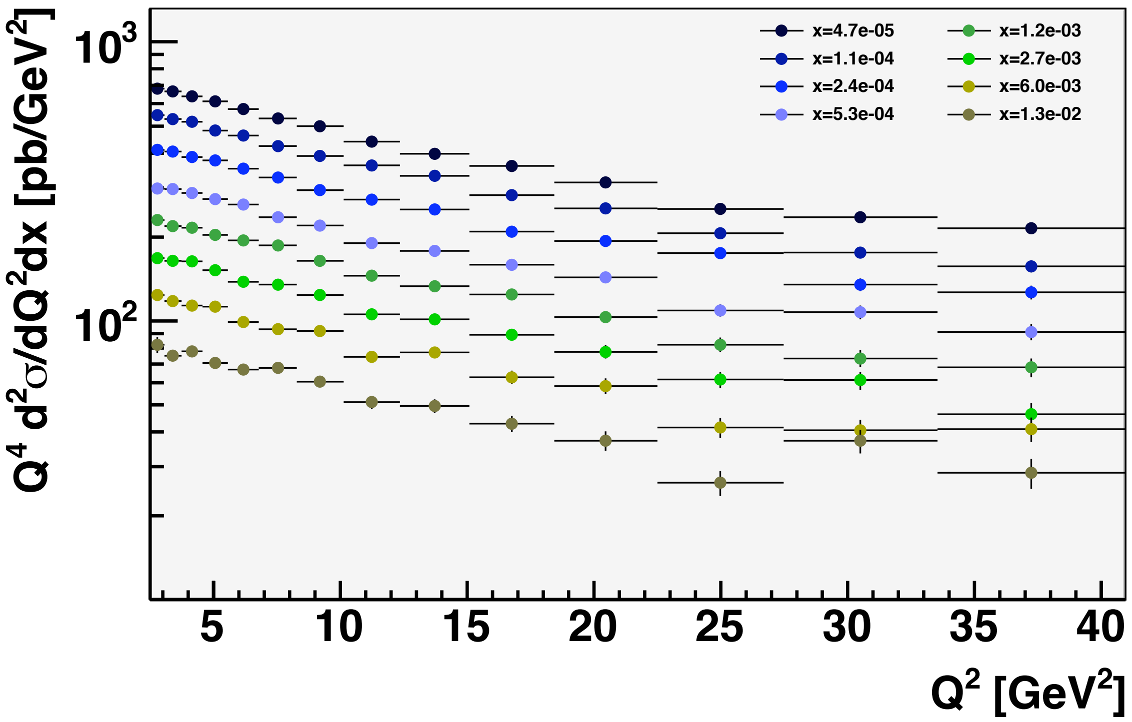
Nuclear modification factor for gluon density squared



t-dependence: characteristic dips.
Challenges: need to distinguish between coherent and incoherent diffraction. Need dedicated instrumentation, zero degree calorimeter.

Exclusive processes: DVCS

MILOU generator using Frankfurt, Freund, Strikman model.



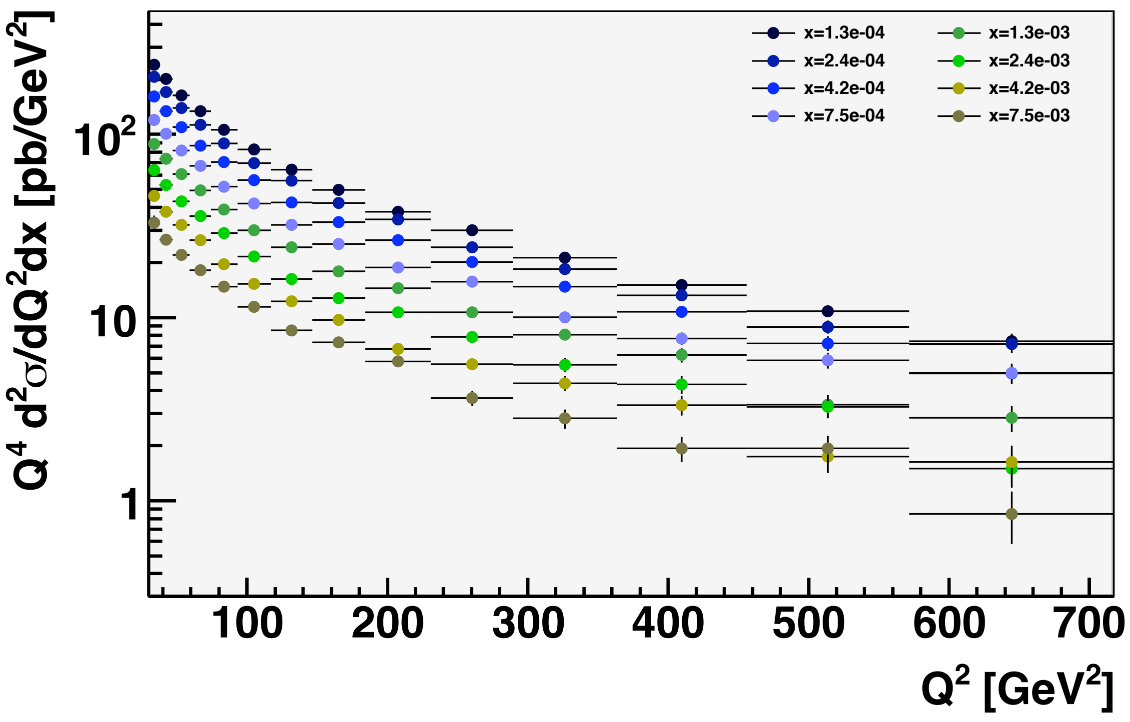
$$\mathcal{L} = 1\ \mathrm{fb}^{-1}$$

$$\theta = 1^o$$

$$p_T^\gamma = 2\ \mathrm{GeV}$$

$$2.5 < Q^2 < 40\ \mathrm{GeV}^2$$

low x



$$\mathcal{L} = 100\ \mathrm{fb}^{-1}$$

$$\theta = 10^o$$

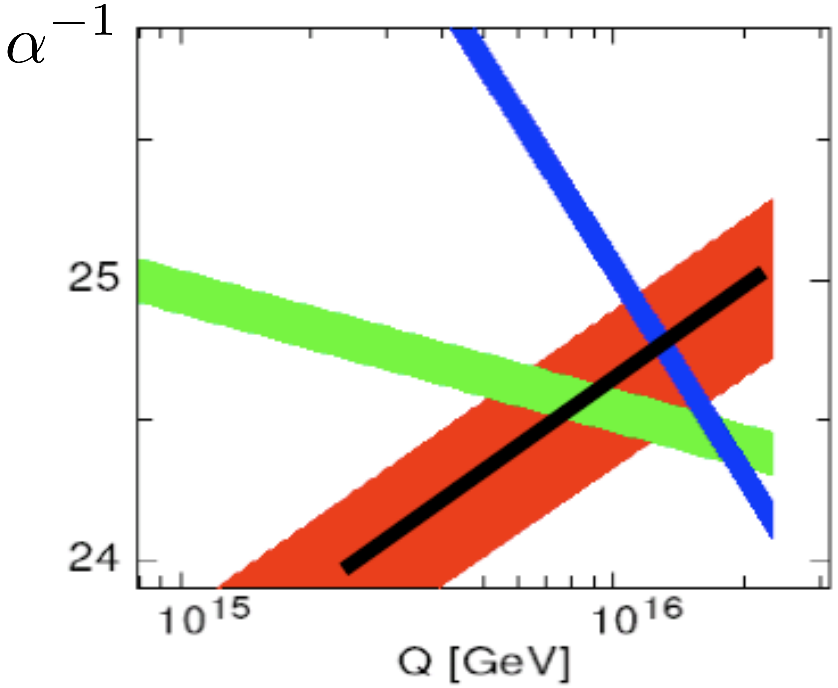
$$p_T^\gamma = 5\ \mathrm{GeV}$$

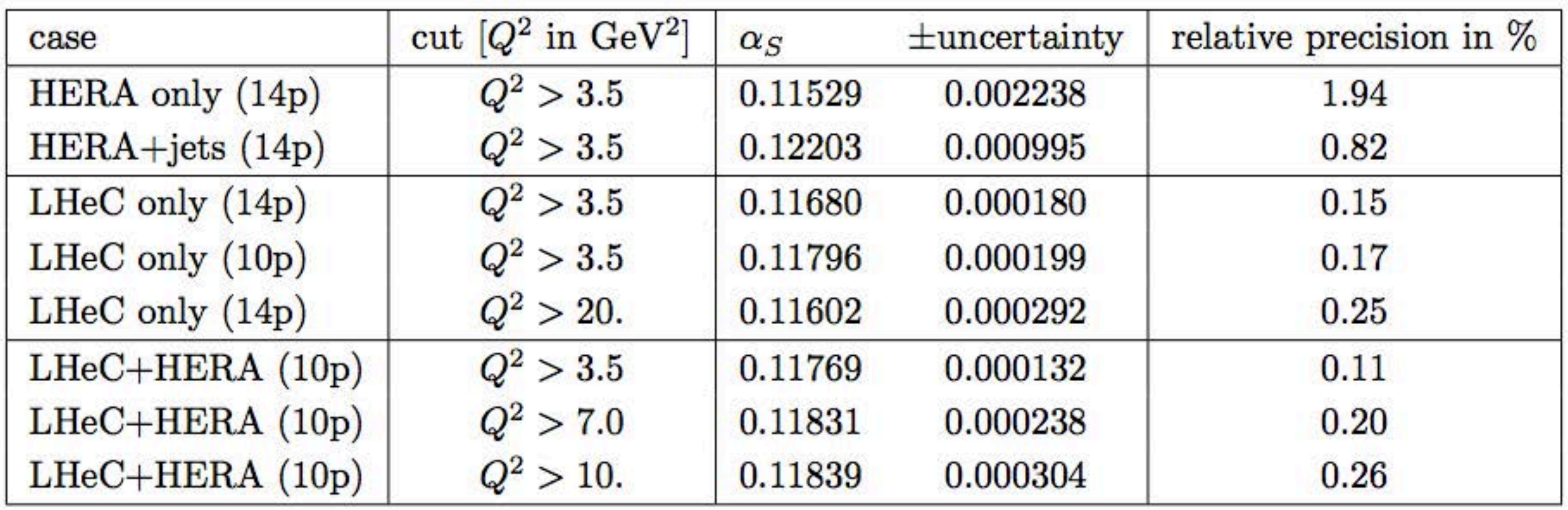
$$50 < Q^2 \simeq 500\ \mathrm{GeV}^2$$

large scales

Measurement of strong coupling

Unification of coupling constants?





case	cut [Q^2 in GeV^2]	α_S	±uncertainty	relative precision in %
HERA only (14p)	$Q^2 > 3.5$	0.11529	0.002238	1.94
HERA+jets (14p)	$Q^2 > 3.5$	0.12203	0.000995	0.82
LHeC only (14p)	$Q^2 > 3.5$	0.11680	0.000180	0.15
LHeC only (10p)	$Q^2 > 3.5$	0.11796	0.000199	0.17
LHeC only (14p)	$Q^2 > 20.$	0.11602	0.000292	0.25
LHeC+HERA (10p)	$Q^2 > 3.5$	0.11769	0.000132	0.11
LHeC+HERA (10p)	$Q^2 > 7.0$	0.11831	0.000238	0.20
LHeC+HERA (10p)	$Q^2 > 10.$	0.11839	0.000304	0.26

Strong coupling is least known of all couplings

Grand unification predictions suffer from uncertainty

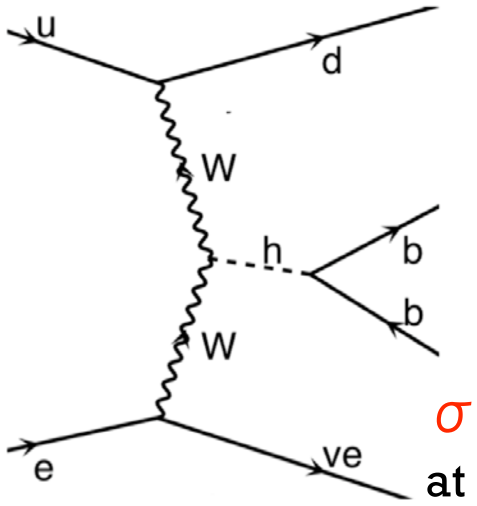
LHeC: per mille accuracy

Verify at large values of photon virtuality, smaller influence of HT effects

Higgs at the LHeC

Signal

CC: H → $b\bar{b}$ (BR ~ 0.7 at M_H=120GeV)



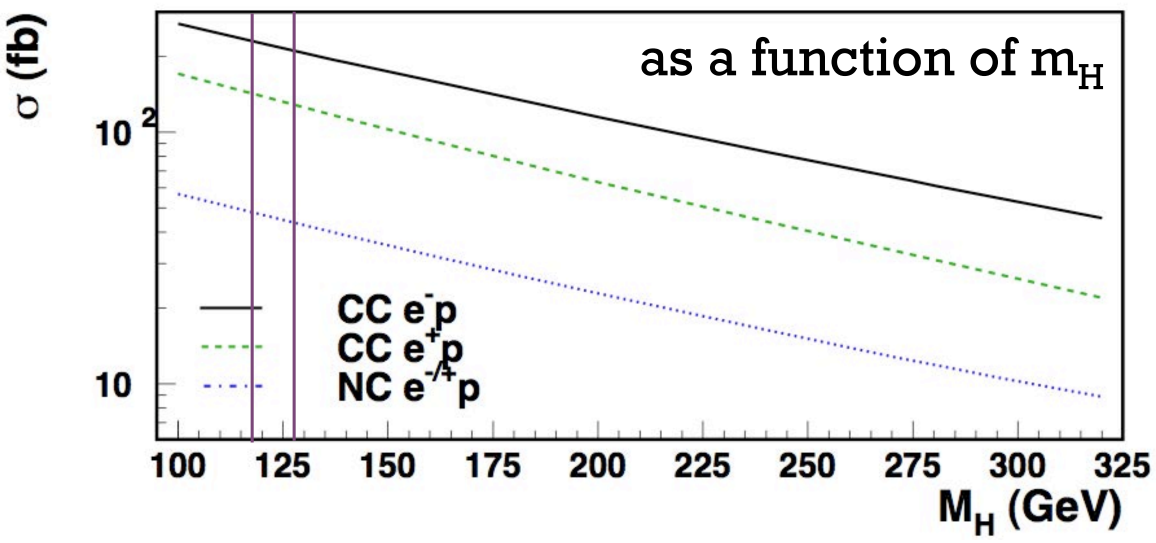
$\sigma \sim 0.16$ pb
at √s=2.05TeV

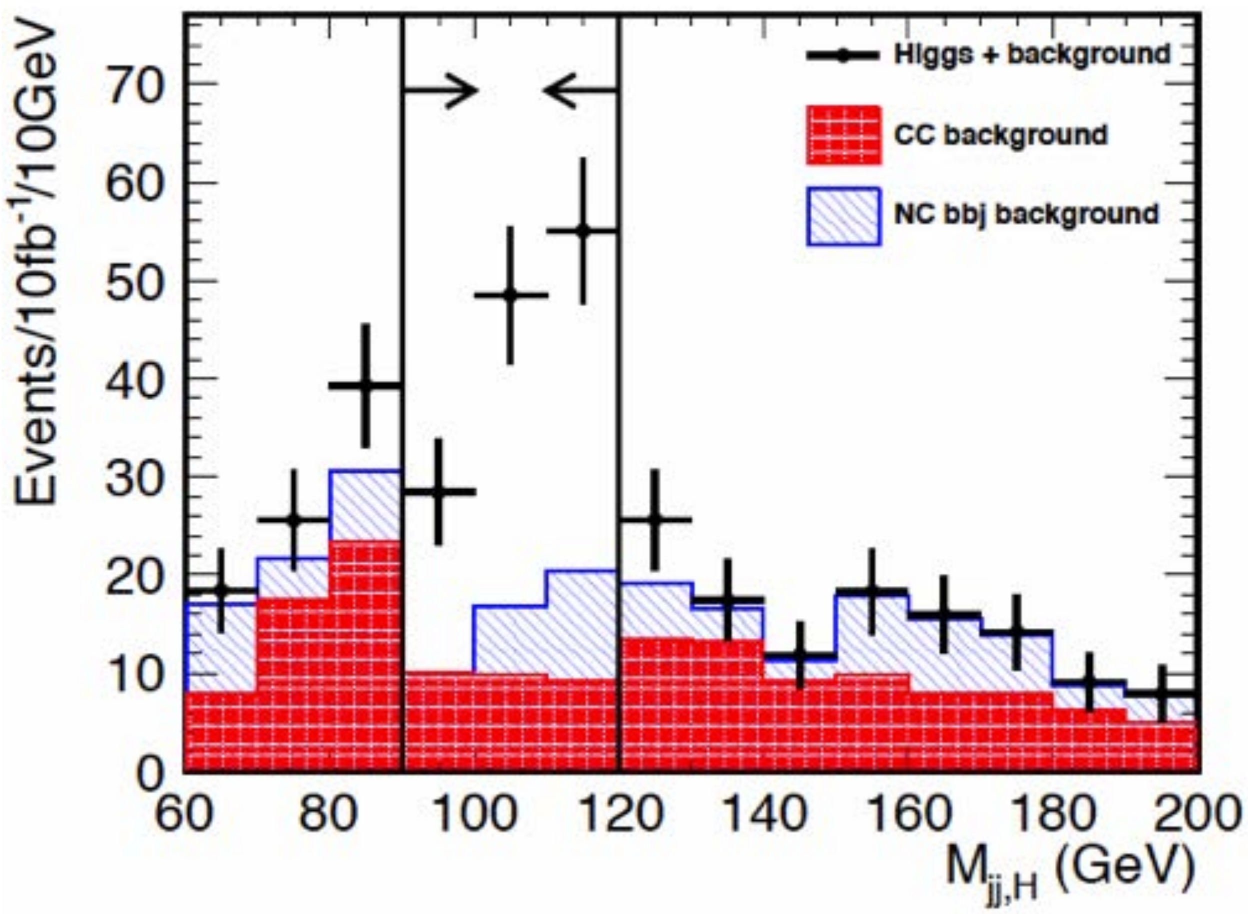
CC Higgs production cross-section
(M_H = 120 GeV)

Electron beam energy	50 GeV	100 GeV	150 GeV
cross-section (fb)	81	165	239

Higs can be studied at the LHeC.
High rates in CC interactions.
bbar channel cleaner at the LHeC.
Necessary to confirm the SM Higgs.

Higgs production cross-section
at $\sqrt{s}$ = 1.98TeV (E_e=140GeV, E_p=7TeV)





Higgs at the LHeC

Talk by Masaki Ishitsuka at Chavannes-de-Bogis

- Beam energy:
  - Electron beam 150 GeV
  - Proton beam 7 TeV
- SM Higgs mass 120 GeV
- Luminosity 10 fb^{-1}

Signal and background cut flow

	$H\to bb$	CC DIS	NC bbj	S/N	S/√N
NC rejection	816	123000	4630	6.38×10^{-3}	2.28
+ b-tag requirement **+ Higgs invariant mass**	178	1620	179	9.92×10^{-2}	4.21
All cuts	84.6	29.1	18.3	1.79	12.3

- Beam energy:
  - Electron beam 150 GeV ⇒ 60 GeV
  - Proton beam 7 TeV
- SM Higgs mass 120 GeV
- Luminosity 10 fb^{-1} ⇒ 100 fb^{-1}

	E_e = 150 GeV (10 fb^{-1})	E_e = 60 GeV (100 fb^{-1})
H → bb signal	84.6	248
S/N	1.79	1.05
S/√N	12.3	16.1

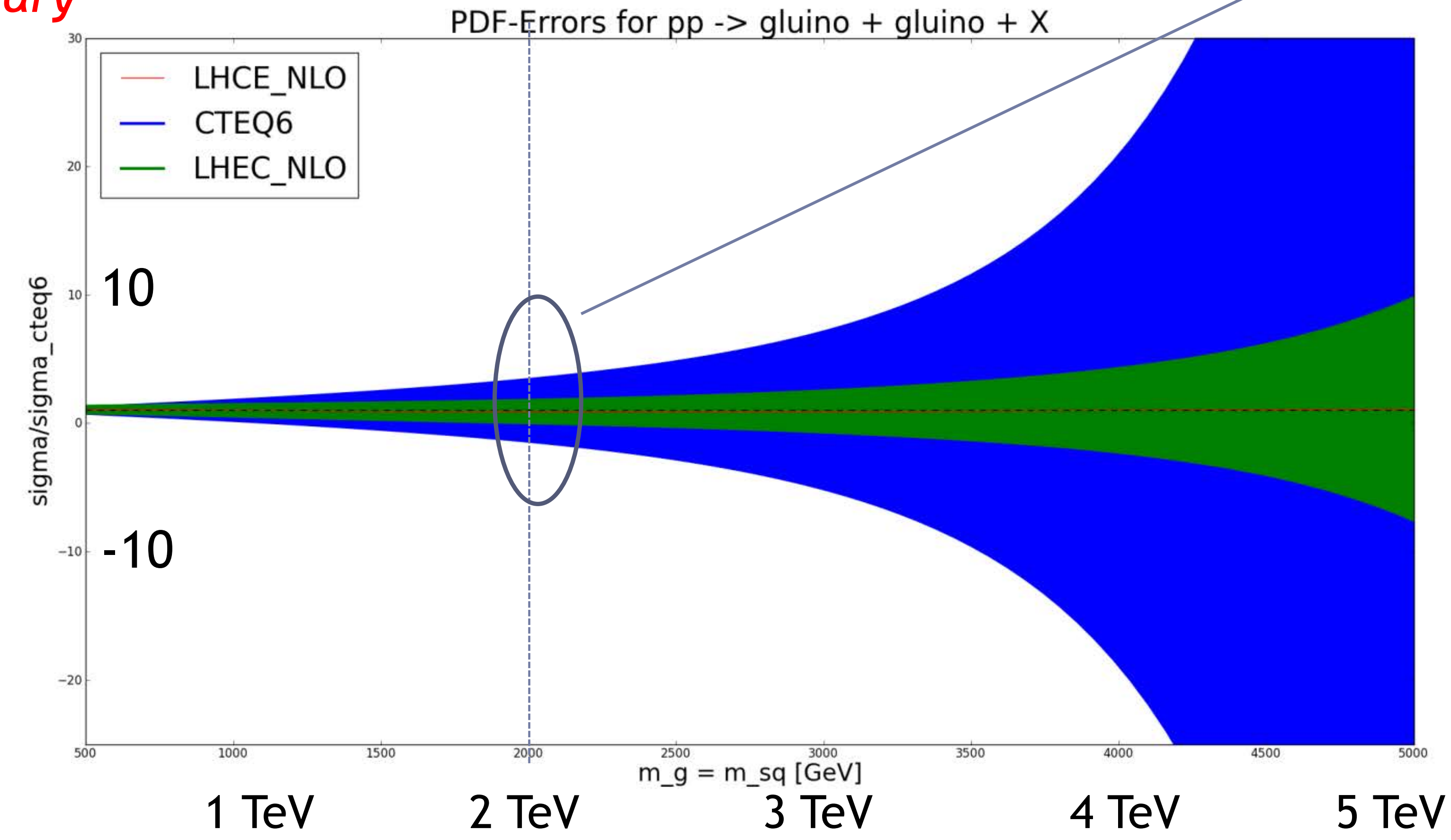
- We can explore other channels
  - NC Higgs production in ZZ fusion
  - Other light Higgs decay channels

Monica d'Onofrio talk at Chavannes-de-Bogis

Impact of LHeC on searches for New Physics

- M.Kramer and R.Klees working on impact of improved PDF fits on theoretical predictions for SUSY process:
  - Example: gl-gl production (assuming m_gl = m_sq)
  - without(blue, CTEQ6) and with (green) LHeC PDF

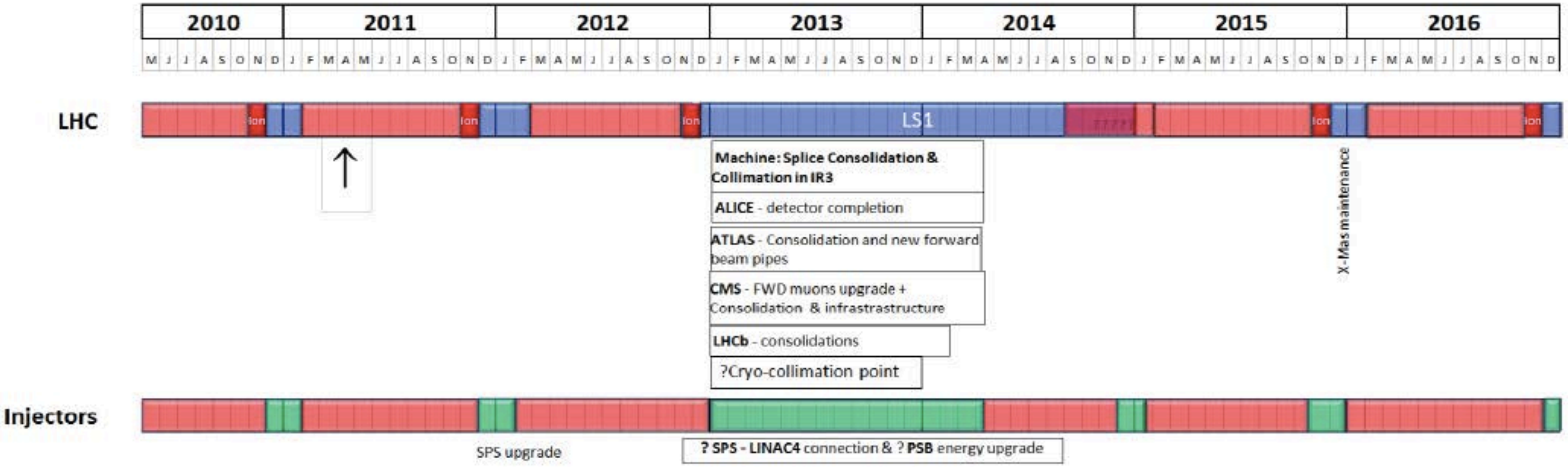
preliminary



Improve of
factor of 2-3 @ 2 TeV
factor of 10 at 3.5 TeV

Precise determination of the PDFs at higher scales absolutely necessary for searches of New Physics.

Draft LHC Schedule for the coming decade



Machine: Splice Consolidation & Collimation in IR3

ALICE - detector completion

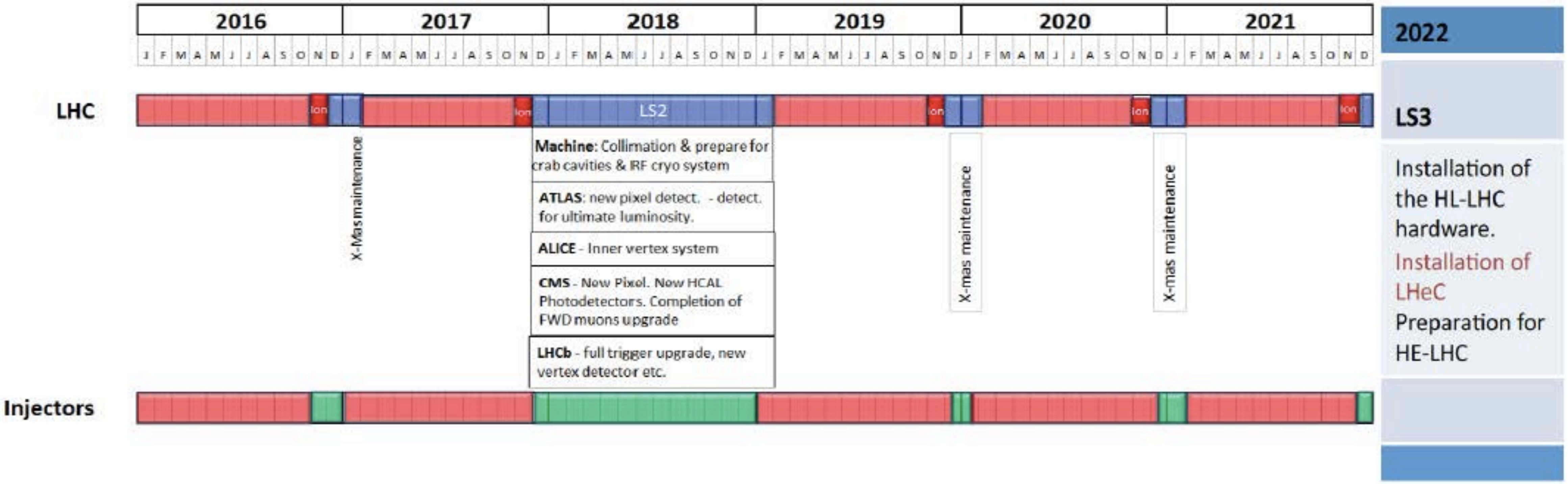
ATLAS - Consolidation and new forward beam pipes

CMS - FWD muons upgrade + Consolidation & infrastrastructure

LHCb - consolidations

?Cryo-collimation point

? SPS - LINAC4 connection & **? PSB** energy upgrade



Machine: Collimation & prepare for crab cavities & RF cryo system

ATLAS: new pixel detect. - detect. for ultimate luminosity.

ALICE - Inner vertex system

CMS - New Pixel. New HCAL Photodetectors. Completion of FWD muons upgrade

LHCb - full trigger upgrade, new vertex detector etc.

LS3

Installation of the HL-LHC hardware.
Installation of LHeC
Preparation for HE-LHC

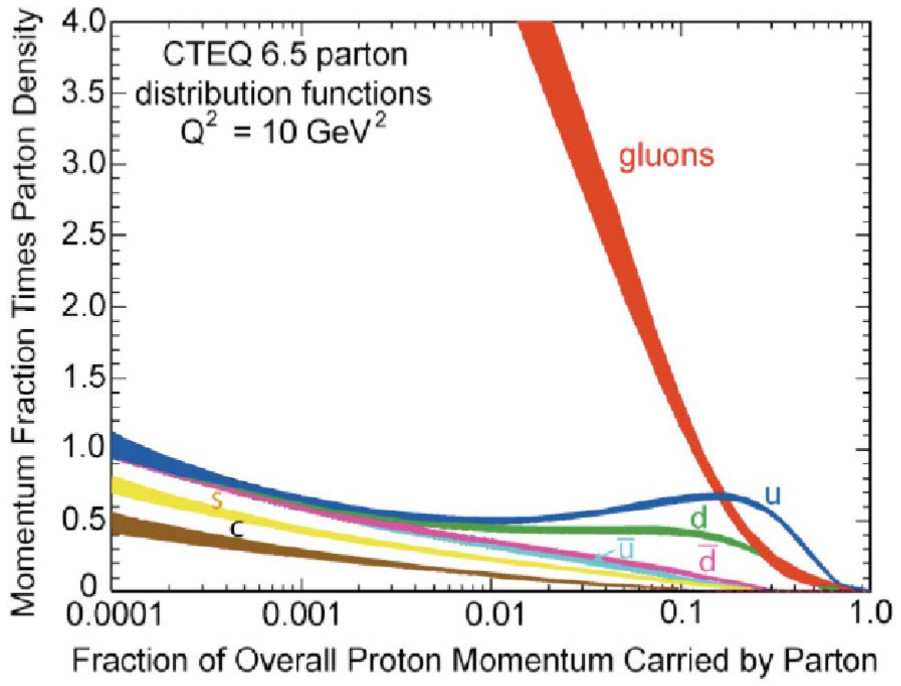
as shown by S. Myers at EPS 2011 Grenoble

Summary

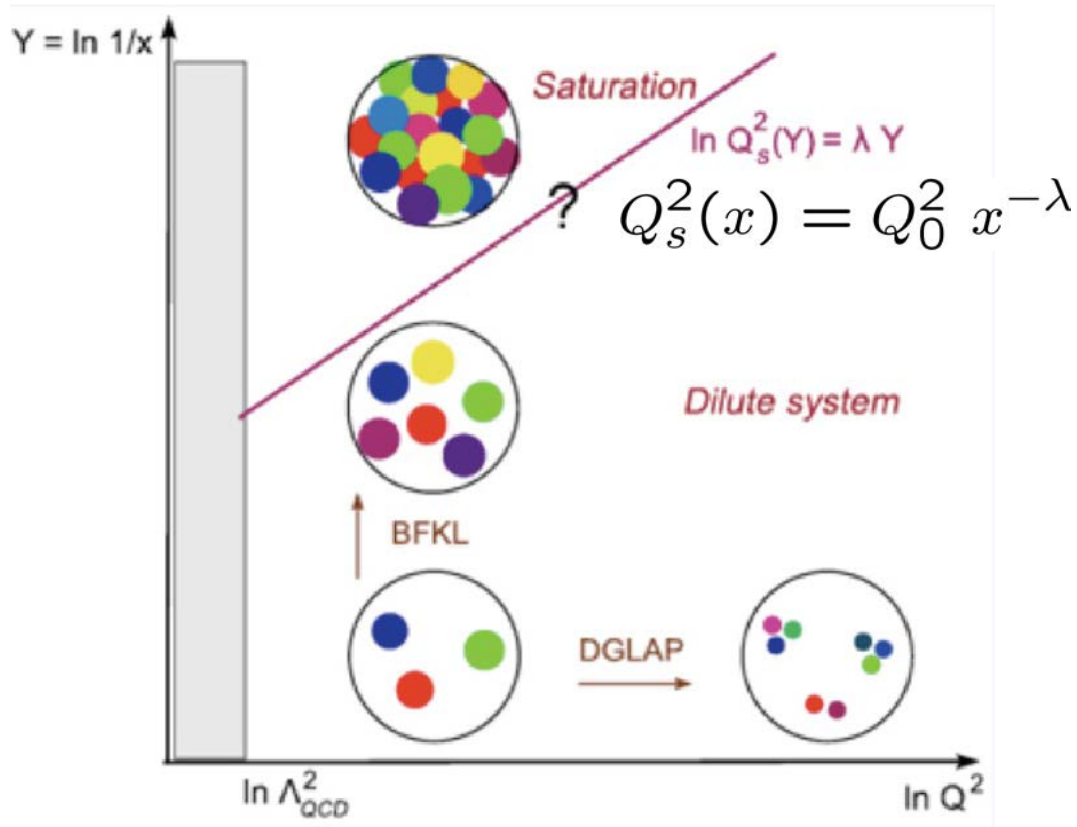
- LHeC has rich and unique physics program, DIS essential part of HEP.
- Precision QCD and Electroweak studies. Understanding the regime of small x. Constraints on BSM physics.
- eA program (DIS of lead nuclei and deuteron) has complementarity with pA and AA physics. Pinning down the initial state in nuclear collisions.
- Conceptual Design Report supported and monitored by CERN, ECFA and NuPECC, has been published.
- Next steps:
- Presentation in European Strategy for Particle Physics meeting in Cracow in September 2012.
- Collaborations are soon to be build for further design, machine and detector.
- CERN mandate for Technical Design Report in 2015.

Backup

Low x and saturation



HERA established strong growth of the gluon density towards small x
Parton saturation: recombination of gluons at sufficiently high densities leading to nonlinear modification of the evolution equations.
Emergence of a dynamical scale: saturation scale dependent on energy.



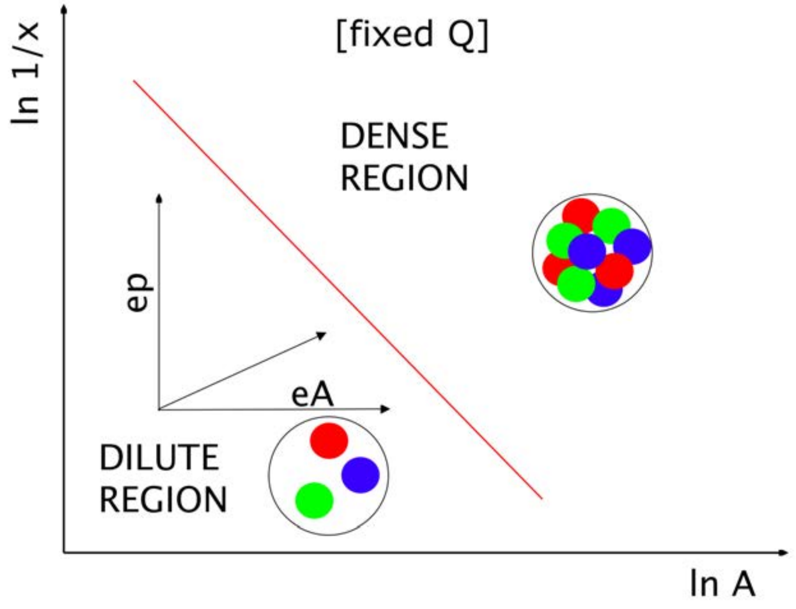
What we learned from HERA about saturation?

Linear DGLAP evolution works well at HERA.
Hints of saturation at low Q and low x: deterioration of the global fit in that region.
Large diffractive component.
Success of the dipole models in the description of the data.
The models point at the low value of the saturation scale
LHeC would provide an access to a kinematic regime where the saturation scale is perturbative

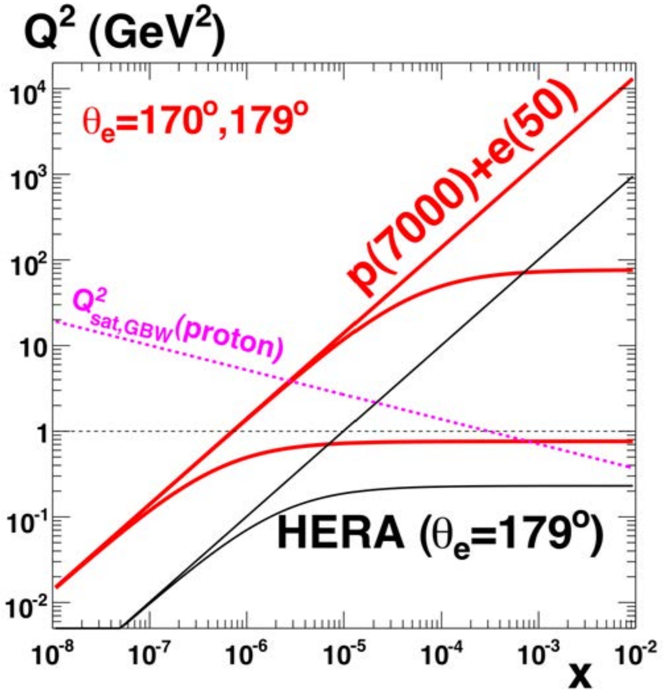
Strategy for making target more ‘black’

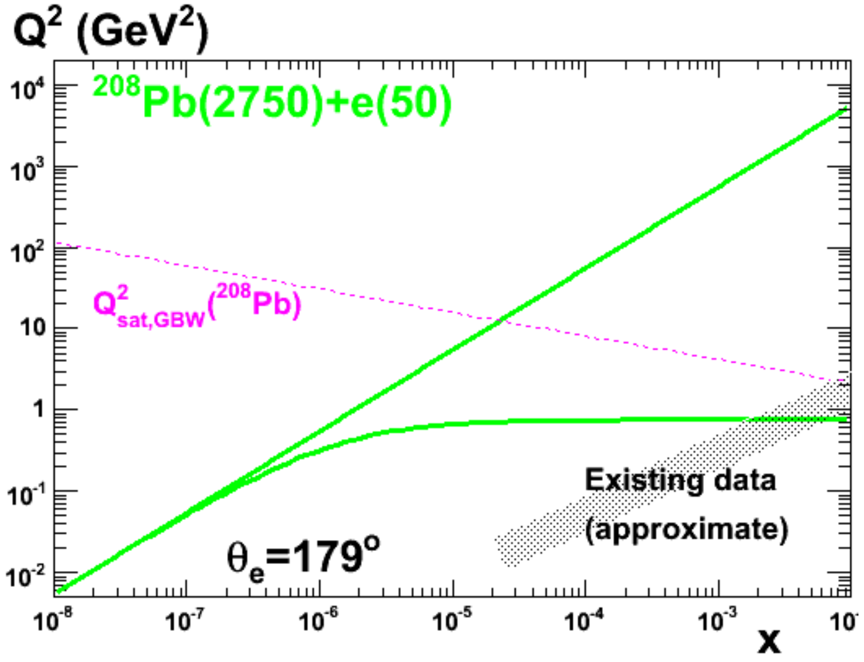
LHeC would deliver a two-pronged approach:

Probing lower x in ep.
Evolution of a single source



More nucleons: eA scattering. Many sources overlapping in impact parameter .





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Olaf Behnke (DESY)
Paolo Gambino (Torino)
Thomas Gehrmann (Zurich)
Claire Gwenlan (Oxford)

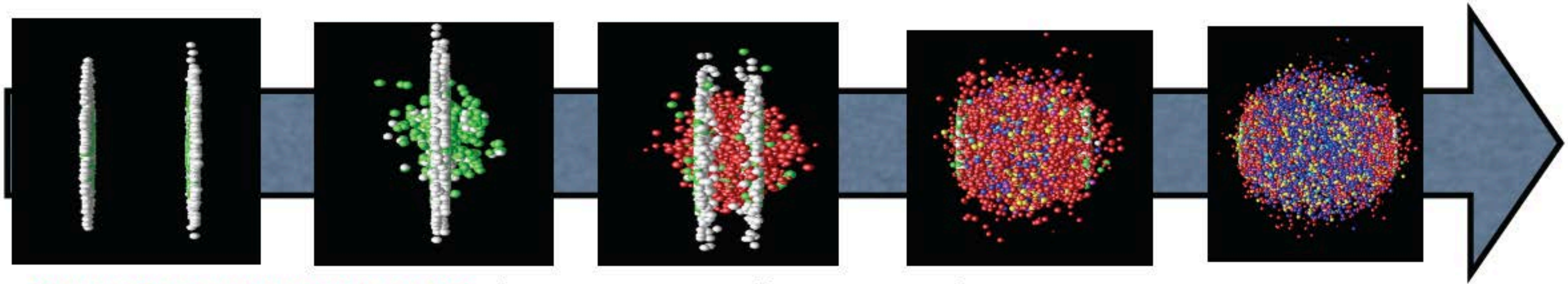
Physics at High Parton Densities

Néstor Armesto (Santiago de Compostela)
Brian A. Cole (Columbia)
Paul R. Newman (Birmingham)
Anna M. Stasto (PennState)

CERN Referees

Ring Ring Design
Kurt Huebner (CERN)
Alexander N. Skrinsky (INP Novosibirsk)
Ferdinand Willeke (BNL)
Linac Ring Design
Reinhard Brinkmann (DESY)
Andy Wolski (Cockcroft)
Kaoru Yokoya (KEK)
Energy Recovery
Georg Hoffstaetter (Cornell)
Ilan Ben Zvi (BNL)
Magnets
Neil Marks (Cockcroft)
Martin Wilson (CERN)
Interaction Region
Daniel Pitzl (DESY)
Mike Sullivan (SLAC)
Detector Design
Philippe Bloch (CERN)
Roland Horisberger (PSI)
Installation and Infrastructure
Sylvain Weisz (CERN)
New Physics at Large Scales
Cristinel Diaconu (IN2P3 Marseille)
Gian Giudice (CERN)
Michelangelo Mangano (CERN)
Precision QCD and Electroweak
Guido Altarelli (Roma)
Vladimir Chekelian (MPI Munich)
Alan Martin (Durham)
Physics at High Parton Densities
Alfred Mueller (Columbia)
Raju Venugopalan (BNL)
Michele Arneodo (INFN Torino)

Nuclear physics in eA complementarity to pA, AA at LHC



Gluons from saturated nuclei → Glasma? → QGP → Reconfinement

Precision measurement of the initial state.

Nuclear structure functions.

Particle production in the early stages.

Factorization eA/pA/AA.

Modification of the QCD radiation and hadronization in the nuclear medium.

Detector : tracking system

Transverse momentum $\Delta p_t/p^2_t$ → $6\mathrm{x}10^{-4}$ GeV^{-1}
transverse impact parameter→ 10 μm

Central Pixel Tracker

4 layer **CPT**:
min-inner-R = 3.1 cm
max-inner-R = 10.9 cm

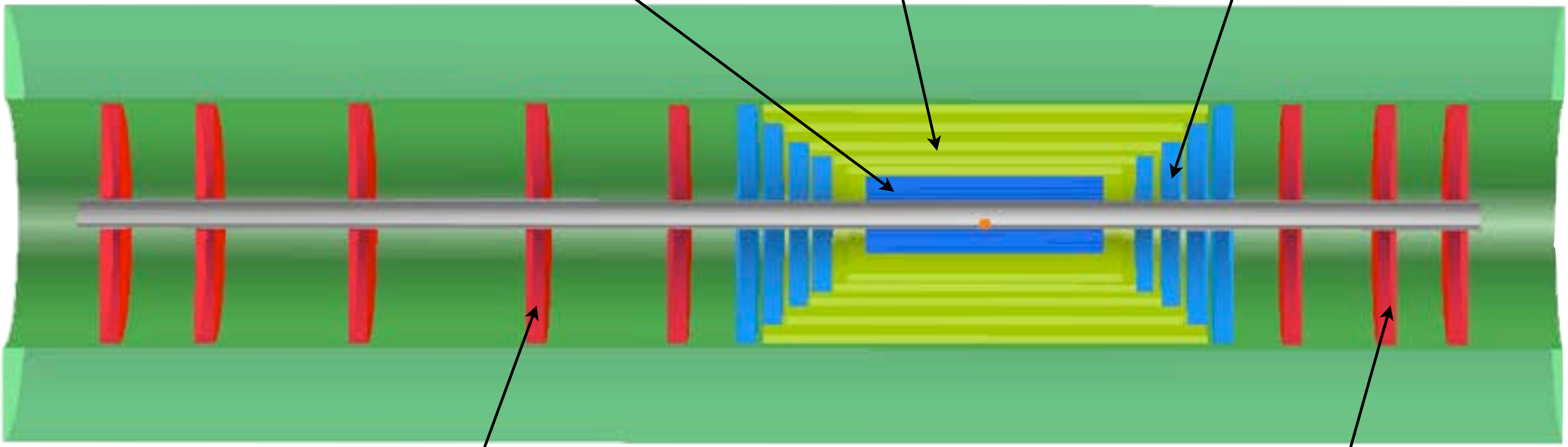
ΔR = 15. cm

Central Si Tracker

CST - ΔR 3.5cm each
1. layer: inner R = 21.2 cm
2. layer: = 25.6 cm
3. layer: = 31.2 cm
4. layer: = 36.7 cm
5. layer: = 42.7 cm

Central Forward/Backward Tracker

4 **CFT/CBT**
min-inner-R = 3.1 cm, max-inner-R = 10.9 cm



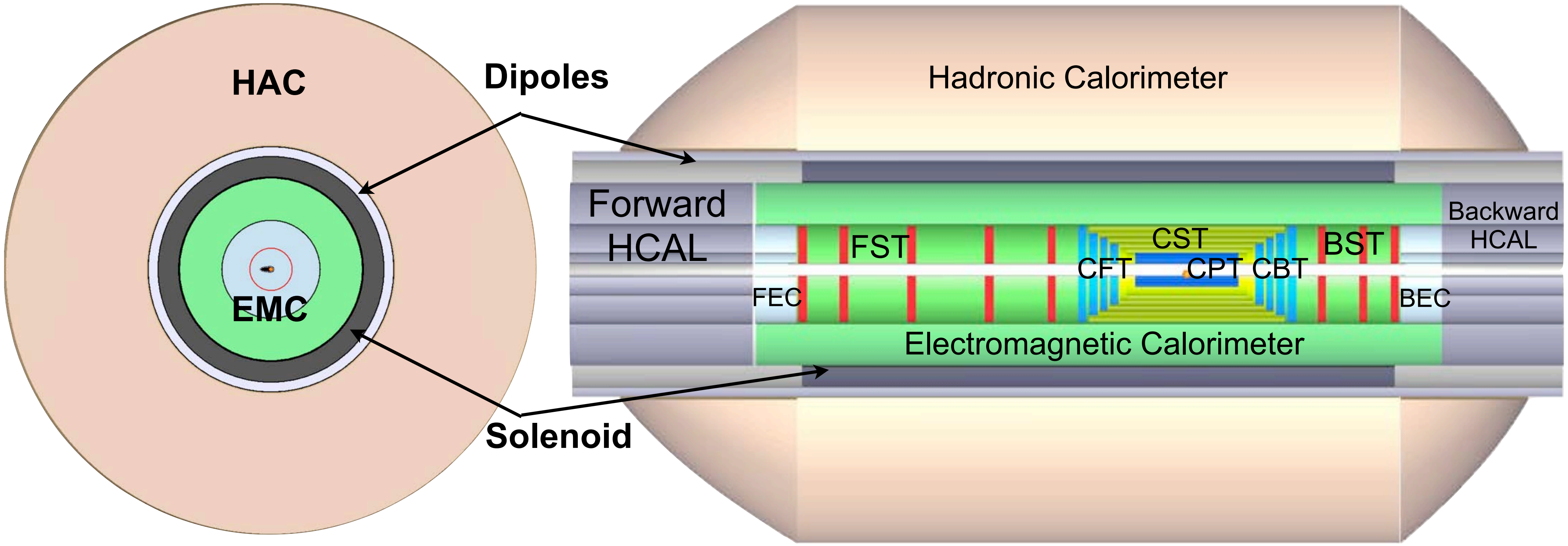
Forward Si Tracker

FST - ΔZ= 8. cm
min-inner-R = 3.1 cm; max-inner-R= 10.9 cm
outer R = 46.2 cm
Planes 1-5:
$z_{5\text{-}1}$ = 370. / 330. / 265. / 190. / 130. cm

Backward Si Tracker

BST - ΔZ= 8. cm
min-inner-R = 3.1 cm; max-inner-R= 10.9 cm
outer R = 46.2 cm
Planes 1-3:
$z_{1\text{-}3}$ = -130. / -170. / -200. cm

Detector : calorimetry

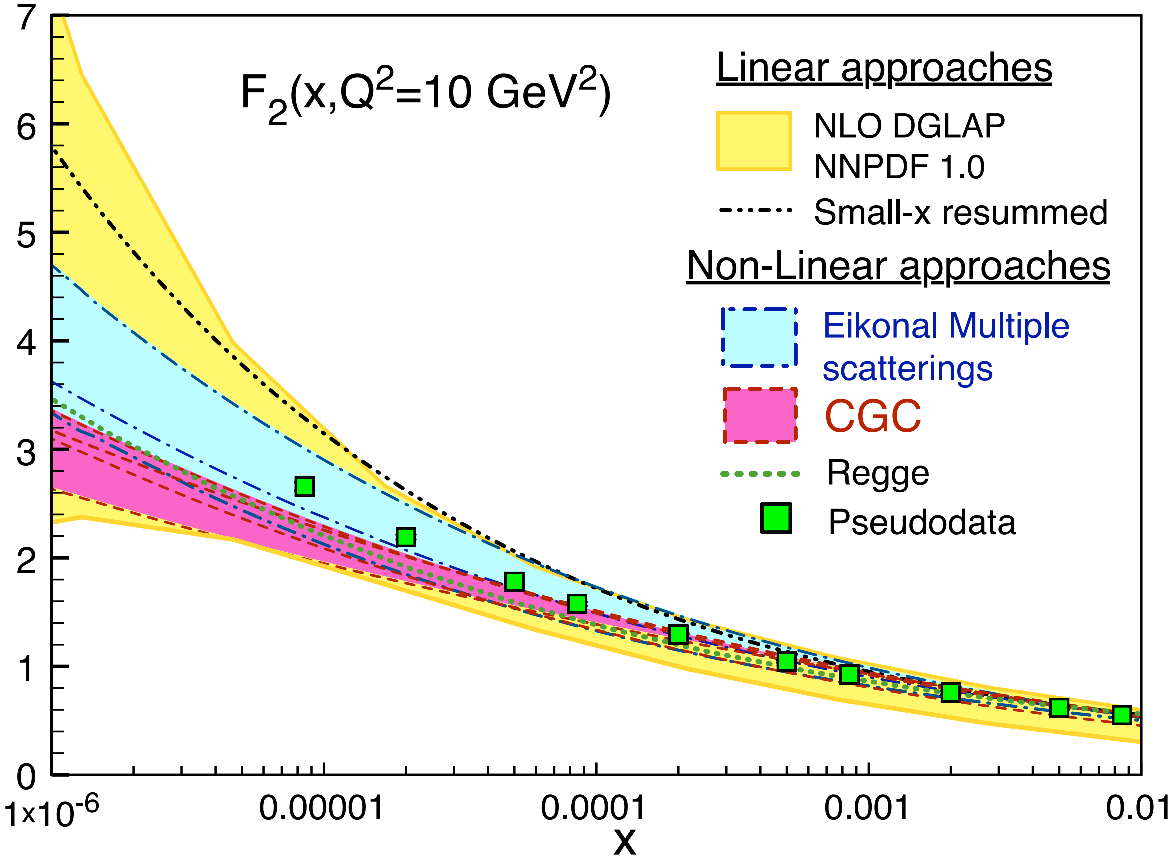


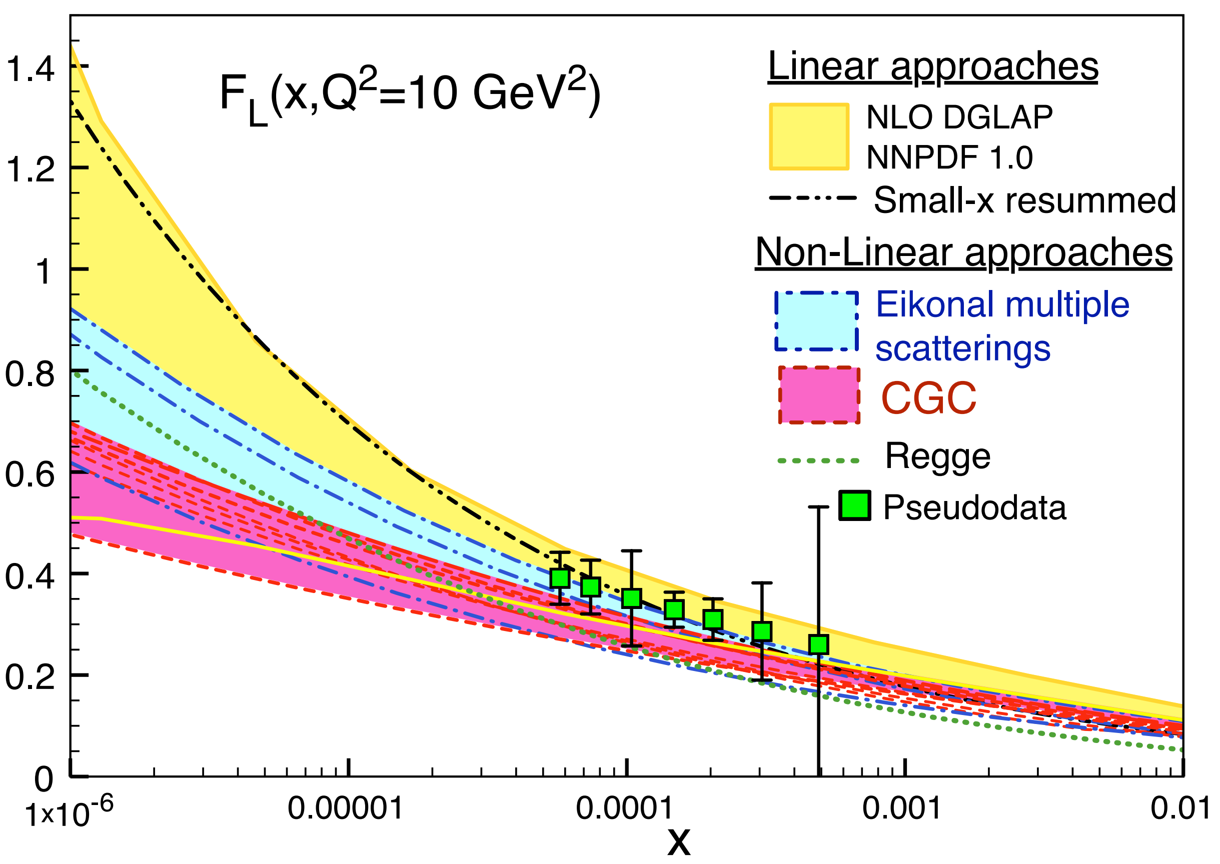
Liquid Argon EM calorimeter

Hadronic Tile calorimeter

F_2,F_L structure functions at low x

Precision measurements of structure functions at very low x: test DGLAP, small x, saturation inspired approaches.



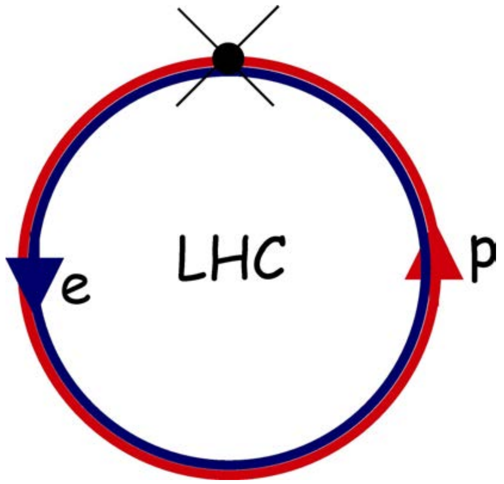


approx. 2% error on the F2 pseudodata, and 8% on the FL pseudodata ,should be able to distinguish between some of the scenarios.

How Could ep be Done using LHC?

… whilst allowing simultaneous ep and pp running …

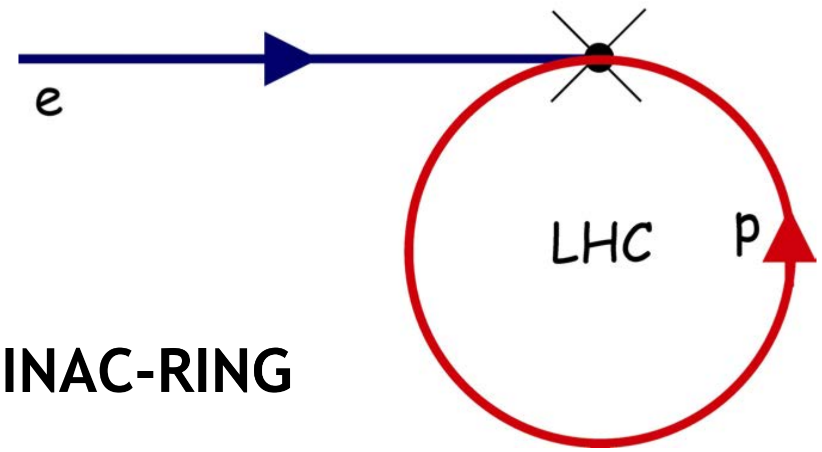
RING-RING



- First considered (as LEPxLHC) in 1984 ECFA workshop

- Main advantage: high peak lumi obtainable (~2.10^{33} cm^{-2} s^{-1})

- Main difficulties: building round existing LHC, e beam energy (60GeV?) and lifetime limited by synchrotron radiation



LINAC-RING

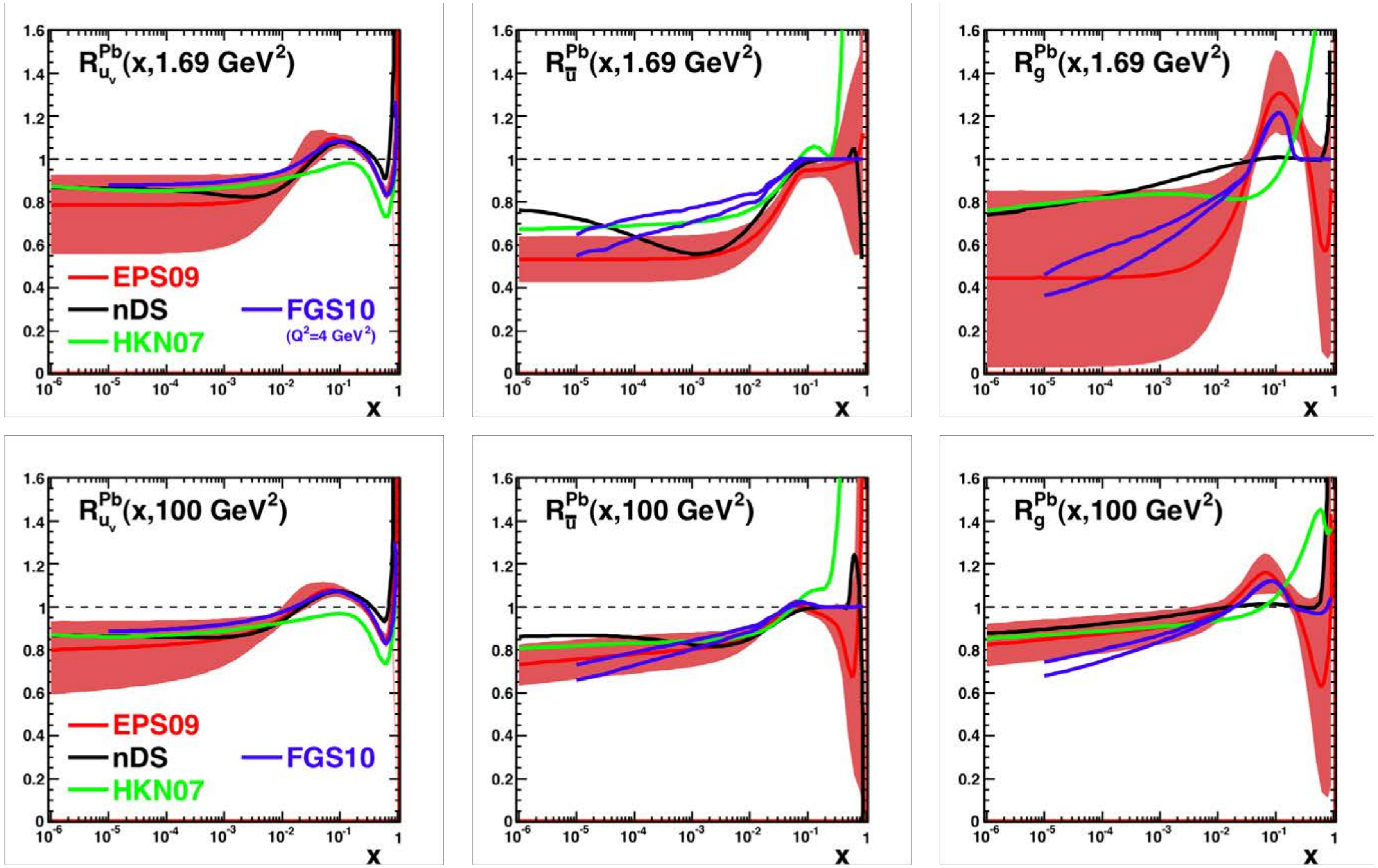
- Previously considered as `QCD explorer' (also THERA)

- Main advantages: low interference with LHC, high E_e (→ 150 GeV?) and lepton polarisation, LC relation

- Main difficulties: lower luminosity <10^{33} cm^{-2} s^{-1}? at reasonable power, no previous experience exists

preferred option

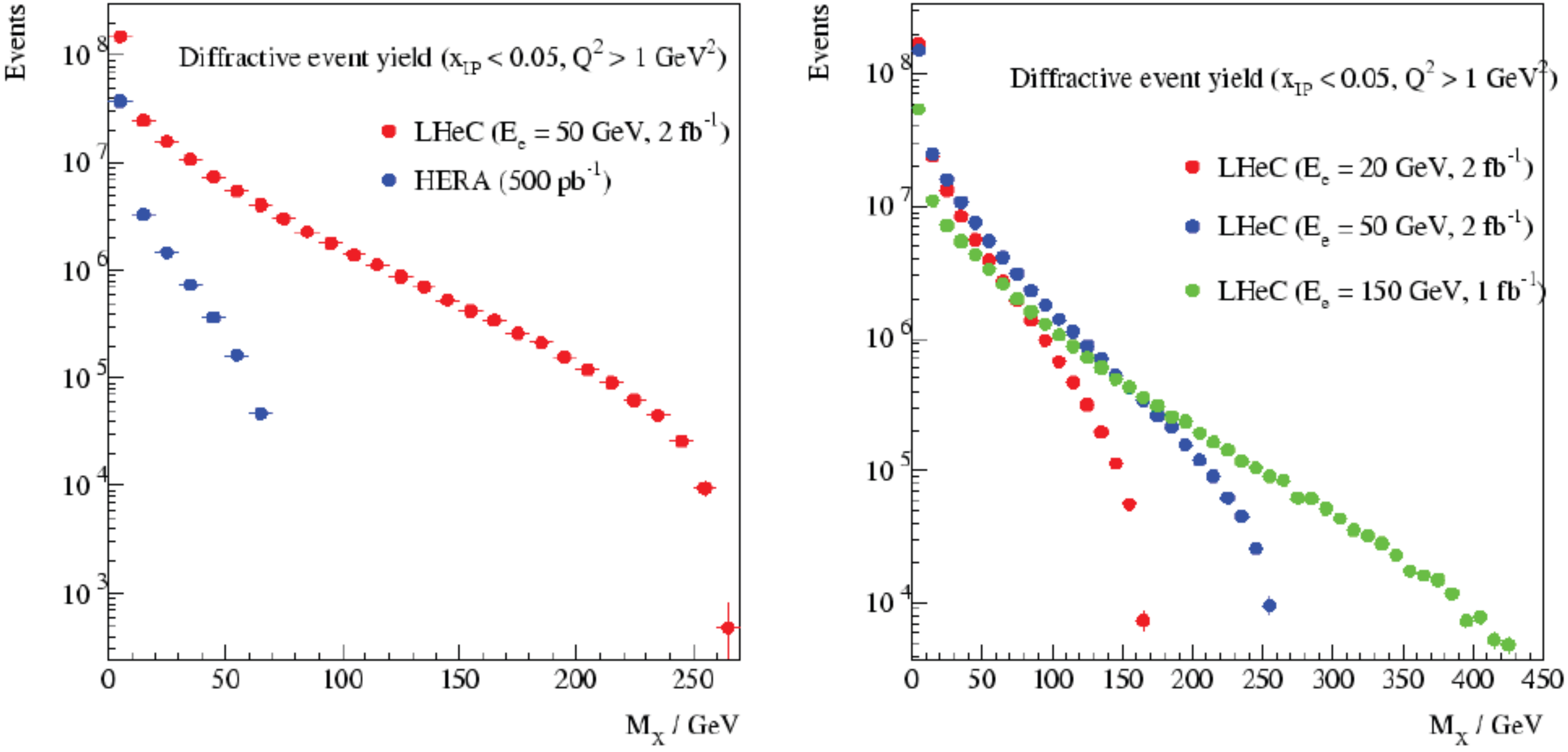
Nuclear parton distributions



R_i = Nuclear PDF i / (A * proton PDF i)

Current status: nuclear parton distribution functions are poorly known at small x. Especially gluon density, below x=0.01 can be anything between 0 and 1....

Diffractive mass distribution



New domain of diffractive masses.

M_X can include W/Z/beauty